Analysis of Human Space Flight Safety

Report to Congress
11 November 2008

Independent Study Mandated by Commercial Space Launch Amendments Act of 2004 (Public Law 108-492)

Prepared by:
The Aerospace Corporation,
George Washington University,
and the Massachusetts Institute of Technology

Sponsored by:
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ANALYSIS OF HUMAN SPACE FLIGHT SAFETY
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Space Launch Operations
THE AEROSPACE CORPORATION
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Executive Summary

Introduction

The Aerospace Corporation (Aerospace), supported by researchers at George Washington University (GWU) and the Massachusetts Institute of Technology (MIT), is pleased to submit this report to Congress on human space flight safety. This independent study was mandated by the Commercial Space Launch Amendments Act of 2004 (Public Law 108-492) and addressed eight topics specified in the legislation. The study was performed under contract DTFAWA-07-C-00084, Analysis of Human Space Flight Safety, awarded by the Federal Aviation Administration (FAA) to Aerospace on September 27, 2007. For administration of this contract, Kenneth Wong represented FAA/AST management, and Marcus C. Ward served as the FAA Contracting Officer's Technical Representative (COTR).

Scope

This study addressed the following eight topics related to activities and responsibilities of the FAA Office of Commercial Space Transportation (FAA/AST):

1. The standards of safety and concepts of operation that should guide the regulation of human space flight and whether the standard of safety should vary by class or type of vehicle, the purpose of flight, or other considerations;
2. The effectiveness of the commercial licensing and permitting regime under chapter 701 of title 49, United States Code, particularly in ensuring the safety of the public and of crew and space flight participants during launch, in-space transit, orbit, and reentry, and whether any changes are needed to that chapter;
3. Whether there is a need for commercial ground operations for commercial space flight, including provision of launch support, launch and reentry control, mission control, range operations, and communications and telemetry operations through all phases of flight, and if such operations developed, whether and how they should be regulated;
4. Whether expendable and reusable launch and reentry vehicles should be regulated differently from each other, and whether either of those vehicles should be regulated differently when carrying human beings;
5. Whether the Federal Government should separate the promotion of human space flight from the regulation of such activity;
6. How third parties could be used to evaluate the qualification and acceptance of new human space flight vehicles prior to their operation;
7. How nongovernment experts could participate more fully in setting standards and developing regulations concerning human space flight safety; and
8. Whether the Federal Government should regulate the extent of foreign ownership or control of human space flight companies operating or incorporated in the United States.

Methodology

To assure that a comprehensive range of insights was represented in this report, a list of questions drawn from the eight topics in the legislation was sent to a wide range of large and small commercial space flight developers as well as commercial and State spaceport developers and operators. Other entities receiving the list of questions included members of the Commercial Space Transportation Advisory Committee (COMSTAC), which provides information, advice, and recommendations to the Secretary of Transportation and the FAA Administrator on matters relating to the U.S. commercial space transportation industry, and the Personal Spaceflight Federation, which represents the majority of potential commercial human space flight providers (vehicles, spaceports, space hotels, prize foundations, and space adventure tours). Further insight was garnered in meetings with representatives from the

National Aeronautics and Space Administration (NASA) Office of Safety and Mission Assurance (S&MA) at NASA Headquarters and the Flight Crew Operations Directorate at the Johnson Space Center, and from reviewing the procedural requirements document, "Human-Rating Requirements for Space Systems," NPR 8705.2B, revised May 6, 2008, prepared by the S&MA office. Other NASA documents that were reviewed included "A Perspective on the Human-Rating Process of US Spacecraft: Both Past and Present," NASA Special Publication, 1995, and "Design Development Test and Evaluation (DDT&E) Considerations for Safe and Reliable Human Rated Spacecraft Systems," NASA Engineering and Safety Center Technical Report RP-06-108, Version 1.0, Vols. 1 and 2, May 1, 2007 and June 14, 2007. In addition, numerous documents from industry and other government agencies were also reviewed.

Although the research for this report was performed primarily by the Aerospace/GWU/MIT team, a significant amount of useful information received from the above entities in the form of responses to the list of questions and in personal interviews was incorporated into the team's findings. This approach assured that perspectives of all affected parties were considered, while maintaining primary focus on safety of the uninvolved public and competiveness of the budding U.S. commercial space flight industry.

Study Team

The following individuals contributed to this study:

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Summary of Study Conclusions

The study findings are presented in detail in the body of the report. Brief summaries of the findings for each of the eight topics listed in the legislation are presented below:

1. **What are the standards of safety and concepts of operation that should guide the regulation of human space flight? Should they vary by class or type of vehicle, the purpose of flight, or other considerations?**

Conclusions: Standards of safety and concepts of operation should be evolutionary, allowing regulation to mature as the industry gains relevant flight experience. Initial regulation must strike a balance between establishing a regulatory regime that allows and encourages private risk taking and investment, while still protecting the uninvolved public from damage and providing for well-informed consent of participants and other involved parties.

Licensing should proceed in a multi-step process, starting with Experimental Operations handled on a case-by-case basis. In the process, a data standard would be developed for collecting design, test, and flight data related to vehicle safety, as well as mishap/accident-related safety reporting. The initial standard of safety should not vary by type of vehicle, purpose of flight, or other considerations, as there is not sufficient data to substantiate these classifications. Several options for safety analysis and dissemination of safety evaluations are presented.

2. **How effective is the commercial licensing and permitting regime under chapter 701 of title 49, United States Code, particularly in ensuring the safety of the public, crew, and space flight participants during launch, in-space transit, orbit, and reentry? Are any changes needed to that chapter?**

   Conclusions: The current license application, application review, and launch monitoring operations are sufficient at the current time. However, it is recommended that FAA/AST continue examining options for safety approval standards for systems and subsystems, as well as mission assurance processes. FAA/AST should also continue to develop and exercise procedures in collaboration with other affected federal agencies for investigation of possible accidents or mishaps. FAA/AST's licensing and regulating authority is presently limited to launch and reentry operations and does not extend to orbital operations. Regulatory legislation for commercial orbital operations should be considered as needed to address expected future commercial orbital ventures.

3. **Is there a need for commercial ground operations for commercial space flight, including provision of launch support, launch and reentry control, mission control, range operations, and communications and telemetry operations through all phases of flight? If such operations are developed, should they be regulated, and if so, how?**

   Conclusion: Commercial ground operations are needed and will be largely the responsibility of the launch vehicle operators for the foreseeable future due to the diversity of design concepts. FAA/AST already is laying the groundwork for incorporating commercial spaceflight into the National Airspace System while allowing industry efforts in this area to mature at their own pace.

4. **Should expendable and reusable launch and reentry vehicles be regulated differently from each other? Should either of these types of vehicles be regulated differently when carrying human beings?**

   Conclusion: Launch of expendable vehicles, when used as a first stage to lift reusable rockets carrying crew and spaceflight participants, as well as launch and reentry of reusable launch vehicles with crew and spaceflight participants aboard, should be regulated differently than launch of expendable vehicles without humans aboard. Range safety controls, regulation, and licensing may have substantial areas of commonality regardless of whether the vehicle is expendable or reusable or has humans aboard. Current range safety processes can continue to apply, with pertinent upgrades as needed. Until more experience is gained with commercial private spaceflight vehicles, however, the regulation of expendable and reusable vehicles for launching humans should remain on a case-by-case basis under existing FAA/AST rule-making, due to the great diversity of vehicle design, system components, and flight characteristics. The development of a metadata system, as recommended under Topic 1, to monitor the development and actual performance of commercial launch systems and to better identify different launch risk factors and criteria, would assist greatly in the regulatory process.

5. **Should the Federal Government separate the promotion of human space flight from the regulation of such activity?**

   <u>Conclusion</u>: There is no compelling reason to remove promotional responsibilities from FAA/AST at this time. The office is performing these duties adequately and has not yet encountered any conflicts of interest or received complaints on this issue.

6. **How should third parties be used to evaluate the qualification and acceptance of new human space flight vehicles prior to their operation?**

   <u>Conclusion</u>: The CSLA defines third parties, for purposes of commercial space launch activities, as the uninvolved public. Independent experts such as consultants and non-government personnel are typically part of the process and are essential to the qualification and acceptance of new human spaceflight vehicles. However, we make no specific recommendations on how they should be used because in the current early stage of development each situation will require different expertise and will be best handled on a case-by-case basis.

7. **How can nongovernment experts participate more fully in setting standards and developing regulations concerning human space flight safety?**

   <u>Conclusions</u>: In setting standards and regulations, the government frequently uses outside expertise to augment its own personnel. Often outside personnel are experts from the specific industry being regulated, consultants, and academia. There are many ways private sector experts are involved in the standards and regulatory process ranging from providing expertise in a particular technical field to serving as members of review, advisory, and accident investigation panels. Each specific circumstance is unique, and there is no reason at this time to recommend any changes to this system. However, in a related area, the National Transportation Safety Board (NTSB), an independent government agency, does not have space transportation explicitly included in its statutory jurisdiction, although it does have agreements with the FAA and the Air Force under which the NTSB will lead investigations of commercial space launch accidents. Congress may want to consider explicitly designating a lead agency for accident investigations involving space vehicles to avoid potential overlapping jurisdictions.

8. **Should the federal government regulate the extent of foreign ownership or control of human space flight companies operating or incorporated in the United States?**

   <u>Conclusion</u>: Commercial human spaceflight is an emerging industry that does not yet have a significant impact on the U.S. economy, play a role in national security, or control militarily significant technologies that are unique to the United States. Therefore, it does not have characteristics that traditionally have provided the rationale for regulating foreign ownership. Imposition of foreign investment limits could undermine the industry's ability to succeed and grow.

Acronyms and Abbreviations

AAS	American Astronautical Society
AIA	Aerospace Industries Association
AIAA	American Institute of Aeronautics and Astronautics
ASAP	NASA Aerospace Safety Advisory Panel
CFIUS	Committee on Foreign Investment in the United States
CFR	U.S. Code of Federal Regulations
COMSTAC	Commercial Space Transportation Advisory Committee
CONOPS	Concept of Operations
COTR	Contracting Officer's Technical Representative
COTS	Commercial Orbital Transportation Services
CRS	Congressional Research Service
CSLA	Commercial Space Launch Act, 1984
CSLAA	Commercial Space Launch Amendments Act, December 2004
CST	Commercial Space Transportation
DCR	Data Collection Ratio
DOD	Department of Defense
DOT	Department of Transportation
EASA	European Aviation Safety Agency
Ec	Casualty Expectation
EELV	Evolved Expendable Launch Vehicle
ELV	Expendable Launch Vehicle
ETR	Eastern Test Range
EVR	Equivalent Vehicle Reliability
FAA	Federal Aviation Administration
FAA/AST	Federal Aviation Administration/Associate Administrator for Space Transportation
FAR	Federal Aviation Regulations
FOIA	Freedom of Information Act
FTE	Flight Test Equivalence
FTS	Flight Termination System
GAO	Government Accountability Office
GPS	Global Positioning System
GWU	George Washington University
IAA	International Academy of Astronautics
IAASS	International Association for the Advancement of Space Safety
IAF	International Astronautical Federation
ICAO	International Civil Aviation Organization
IEEE	Institute of Electrical and Electronic Engineers
ISO	International Organization for Standardization
ISS	International Space Station
ITAR	International Traffic in Arms Regulations
ITU	International Telecommunications Union
IVHM	Integrated Vehicle Health Management
JPDO	FAA Joint Planning and Development Office
MIT	Massachusetts Institute of Technology
MOA	Memorandum of Agreement
MOU	Memorandum of Understanding
MPL	Maximum Probable Loss
NAS	National Airspace System
NASA	National Aeronautics and Space Administration

NHTSA	National Highway Traffic Safety Administration
NOAA	National Oceanic and Atmospheric Administration
NTSB	National Transportation Safety Board
OSC	Department of Commerce Office of Space Commercialization
OSHA	Occupational Safety and Health Administration
PCE	Personal Casualty Expectation
PRE	Personal Risk Exposure
PSF	Personal Spaceflight Federation
PSF	Personal Survival Factor
RLV	Reusable Launch Vehicle
SAE	Society of Automotive Engineers
S&MA	NASA Office of Safety and Mission Assurance
SATMS	Space and Air Traffic Management System
SRB	Solid Rocket Booster
STA	Space Transportation Association
STC	Space Transition Corridors
SUA	Special-Use Airspace
TEFT	Total Equivalent Flight Tests
TTI	Test Thoroughness Index
TTS	Thrust Termination System
UNCOPUOS	United Nations Committee on the Peaceful Uses of Outer Space
U.S.	United States
USAF	United States Air Force
USC	United States Code
USHPA	United States Hang Gliding and Paragliding Association
USPA	United States Parachute Association
WIPO	World Intellectual Property Organization
WFF	Wallops Flight Facility
WTR	Western Test Range

Introduction

The concept of routine human spaceflight, involving large numbers of people and conducted for a variety of purposes, has been a staple of science fiction for a long time. But long after human spaceflight became reality in the 1960s, ideas about leisure travel beyond Earth – usually referred to as space tourism – still were not taken seriously. However, this has changed in recent years.

If the recent change in perception can be attributed to specific events, two milestones stand out, one involving orbital flight and the other suborbital. The orbital flight example was Dennis Tito's April 2001 flight to the International Space Station (ISS), which demonstrated that there are private citizens willing to pay a considerable amount of money for a trip into space. Others have followed Tito's path, proving that it was more than just a one-time occurrence. But the round trip to space was provided by Russian government vehicles, so a second milestone was needed to show that privately developed vehicles suitable for carrying spaceflight participants were on the horizon. This occurred in 2004 with the suborbital flights of Scaled Composites' *SpaceShipOne*, which appeared to confirm the emergence of a new industry. These events, coupled with significant progress on development of commercial human-carrying rockets at several entrepreneurial companies, appear to indicate that commercial human spaceflight is set to expand substantially in the near future. Past commercial orbital and suborbital flights illustrate that there are customers for commercial spaceflight in both flight regimes.

Human spaceflight programs operated by governments have sought to make space missions as safe as possible. Yet despite extraordinary efforts, there have been fatal accidents on the ground and in flight. This experience, spanning nearly five decades, contributes lessons learned for the emerging spaceflight industry as it faces safety challenges and shapes its expectations. At the same time, U.S. government regulators must achieve a balance between protecting participants and the public while allowing industry to evolve creatively and at a pace that responds to the requirements of the business environment.

The Commercial Space Launch Act (CSLA) amendments of December 2004[1] are intended to promote commercial human spaceflight activities while preserving public safety. This study addresses a series of safety-related issues specified in the CSLA amendments, which mandate that a report be submitted to the Senate Committee on Commerce, Science, and Transportation and the House Committee on Science four years after enactment of the amendments. The long lead-time for the study was chosen because it was expected that by the time four years had passed, commercial human spaceflight would have gained sufficient experience to test the effectiveness and reveal any gaps in the regulatory regime. By the time this study began in October 2007, however, it was evident that this experience would not be forthcoming by December 2008.

Nevertheless, much has happened since 2004. Design and development of several commercial vehicles has advanced, spaceport planning has progressed, business plans have been refined, and NASA is investing in two commercial launch developers and cooperating with several others in its Commercial Orbital Transportation Services (COTS) program. The study team took these developments into account in its analysis and recommendations, tempered by the fact that the flight experience Congress had hoped for when it passed the legislation has not yet materialized.

The study team was aware of the international implications of the U.S. experience in the licensing, regulation, and promotion of commercial human spaceflight. As in other areas of space law and regulation, the U.S. has been a pioneer in this area, and its leadership in setting national standards and procedures may become the model for other national and international guidelines.

[1] Public Law 108-492, Commercial Space Launch Amendments Act of 2004.

The study team was led by The Aerospace Corporation, with vital assistance from George Washington University and the Massachusetts Institute of Technology. The team was selected by the FAA to assess whether the existing legislative and regulatory framework is adequate to ensure safety in commercial human spaceflight in the coming years (at least through 2012). The team was asked to make recommendations on how the current framework could be altered or enhanced to foster an innovative new industry while maintaining effective, though not overly restrictive, safety regulations. This report provides recommendations where they are supported by data and experience – in some cases, recommending that no change is required at this time – and suggests some areas for future study.

Note: The expression “spaceflight participants” reflects language in the Commercial Space Launch Amendments Act of 2004 and FAA/AST regulations.

Topic 1
What are the standards of safety and concepts of operation that should guide the regulation of human space flight? Should they vary by class or type of vehicle, the purpose of flight, or other considerations?

Conclusion: Standards of safety and concepts of operation should be evolutionary, allowing regulation to mature as the industry gains relevant flight experience. Initial regulation must strike a balance between establishing a regulatory regime that allows and encourages private risk taking and investment, while still protecting the uninvolved public from damage and providing for well-informed consent of participants and other involved parties.

Licensing should proceed in a multi-step process, starting with Experimental Operations handled on a case-by-case basis. In the process, a data standard would be developed for collecting design, test, and flight data related to vehicle safety, as well as mishap/accident-related safety reporting. The initial standard of safety should not vary by type of vehicle, purpose of flight, or other considerations, as there is not sufficient data to substantiate these classifications.

Several options for safety analysis and dissemination of safety evaluations are presented.

Mission Assurance as a Consideration for Standards Development

Mission assurance is the disciplined application of general systems engineering, quality, and management principles toward achieving mission success. It focuses on the detailed engineering of the launch system using independent technical assessments as a cornerstone throughout the entire concept and requirements definition, design, development, production, test, deployment, and operations phases.

Effective mission assurance is critical because space is an unforgiving business. Orbital launch vehicle mission failures in the 1990s resulted in $11 billion in lost assets. Many of these losses resulted from the use of unvalidated acquisition practices – the "faster, better, cheaper," and "acquisition reform" approaches that grew popular after the Cold War. More significant than the loss in dollars was the loss of vital military and intelligence capabilities and opportunities for space exploration, research, and commerce.[2] A more detailed description of the principles and application of mission assurance is presented in Appendix C.

For the entrepreneurial commercial launch industry, full application of mission assurance principles is not yet necessarily appropriate, in part because many of the contemplated missions are in the suborbital regime, which poses significantly less stringent technical challenges than those associated with orbital missions and is amenable to many design features similar to those for aircraft. For the analysis that follows, the mission assurance perspective, backed up by decades of experience and data, was taken into account. At the same time, consideration was given to the significant variances from past experience, such as merging of aircraft and spacecraft features, that manifest themselves in the requirements and expectations for commercial human spaceflight.

[2] W. F. Ballhaus, Jr., "From the President's Desk," *Crosslink*, The Aerospace Corporation, v. 8, n. 2, Fall 2007, p. 1.

Background Data Collection

The first step in addressing this topic was to review responses to the list of questions described in Appendix A, which was sent to potential providers of human spaceflight opportunities and their representatives. The principle considerations in the development of the survey were to:

- Leverage relevant experience (both internal and external) to characterize the considerations that go into developing standards.
- Provide an acceptable level of spaceflight participant, crew, and third party safety/casualty mitigation while minimizing overly complex, cumbersome, and undefined processes and standards.
- Allow for the broadest possible ranges of design, concepts of operations, and flight purposes/uses.
- Develop the standards in a manner that minimizes the need for detailed case-by-case analyses by FAA/AST, yet provides fair and equitable treatment to all.

Development of these standards could draw upon the experience from other forms of commercial carriers operating under government regulation.

Results / Interpretation of Industry Responses to List of Questions

Feedback from the list of questions – including a response from the Personal Spaceflight Federation, which represents the majority of potential commercial human spaceflight providers (vehicle, spaceports, space hotels, prize foundations, and/or space adventure tours) – helped in formulating several key observations:

- An expected concern within the industry was prevention of actions taken by one or two highly risk-tolerant providers that would adversely impact the industry as a whole. Our expectation was one or two of the prospective providers would be concerned that less than fully responsible behavior (in design, testing, and/or maintenance approaches) by another provider would result in a series of highly publicized accidents that significantly hinder the industry. However, the results indicated that the industry was substantially more concerned with the potential for over-regulation during the nascent development phase than with the establishment of minimum standards. Their primary focus was on preventing the establishment of highly invasive or cumbersome regulations that would discourage private risk taking and investment.
- The responses did not indicate significant concern with the existing process of case-by-case analysis for licensing. Instead, industry perception was that any attempt to regulate by class or type of vehicle, purpose of flight, etc. would be done with insufficient relevant experience and would only serve to artificially restrict innovation and unique design approaches. The perception was that the landscape is rapidly evolving with new design approaches, mission profiles, and concepts of operation on a nearly continuous basis, making it virtually impossible for regulation to keep up while industry is undergoing such dramatic, fast-paced evolution. Moreover, the likelihood of more than one or two providers employing the same basic conceptual design approach was perceived to be very small, resulting in regulations still being effectively developed on a case-by-case basis.
- A review of NASA, Air Force, and FAA regulations illustrated that each has undergone an evolution with increasing level of complexity and compliance requirements as the aircraft, spacecraft, and launch vehicle industries have matured. Given the depth and rigor required in the evolved regulations, imposition of similar regulation on an emerging industry would likely impose considerable hardship and limit options for development.

- This industry can be compared to other action adventure activities, such as mountain climbing, hang gliding, whitewater rafting, etc. While adventure sports face similar issues related to protection of participant safety, these enterprises face very different technical challenges and potential downsides.
    - Adventure sports and human spaceflight may (or may not) have similar risk factors, but accidents during human spaceflight activities have significantly greater potential consequences for uninvolved third parties. Thus it is imperative that the FAA continue to provide and enforce clear regulations prior to widespread activity in this industry to ensure that third parties will continue to be protected.
    - Human spaceflight involves significantly more advanced technology. The general public would not be expected to have (or acquire) the experience needed to make determinations about which design, testing, and/or operations approaches provide the best mixes of both value and safety.
    - Many of the adventure activities involve participation or involvement by the consumer. These activities are voluntary risk activities managed by the individual's abilities, tolerance, and skills which typically evolve with experience / exposure. However, human spaceflight participants have little or no control over the safety or risk of the overall vehicle.
    - Human spaceflight is a highly visible enterprise that will receive considerably more media coverage (both positive and negative) than other adventure activities. As a result, future customers will be keenly aware of any early failures, which may adversely impact the potential customer base and revenue stream.
    - In action adventure activities under FAA jurisdiction (skydiving and hang gliding), the FAA has allowed a high degree of industry self-regulation and self-policing. In these cases, industry organizations such as United States Hang Gliding and Paragliding Association (USHPA) and the United States Parachute Association (USPA) have been very successful in supporting this construct. Their overall safety record has improved over time, eliminating the need for substantial FAA intervention in the form of new regulations.
    - As these industries developed, they generated an increasing amount of data on safety and reliability, including data on how these factors were influenced by different design and process approaches. This maturity was evidenced by a correlation between safety/injury rates and the ability to raise capital and obtain affordable insurance. Highly risk-tolerant designs and/or operations proved to not be a viable business strategy, thus the competitive field was reduced over time to the more professional outfitters.

Desired Characteristics of Proposed Regulatory Approach

Careful consideration of the above factors leads to a preference for regulation with the following characteristics:

- Provide a balance between safety and aggressive regulation. This must reflect experience from the Faster, Better, Cheaper (NASA) and Acquisition Reform (DoD) eras, as well as the consequences of full mission assurance activities.
- Provides a method to collect data from the initial providers. The data would be used to develop an increased understanding of the correlation between various design, test, and operational decisions and the risk of the flight, leading to better regulations as the industry matures.
- Provides a path towards evolutionary improvements in regulation. Using automotive and aircraft industry examples, more rigorous rules and regulations could be implemented and enforced as the experience base matures. For example, the National Highway Traffic Safety Administration

(NHTSA) now demands safety devices on automobiles that were not originally required, and emergency exits and mandatory safety inspections are required by the FAA.

- As the human spaceflight industrial base matures, opportunities exist to refine this proposed methodology, the related data requests and documentation, and the regulations. This is analogous to the pre-FAR era of commercial aircraft. Based on the impact of regulation in the early stage of development, FAA/AST could elect to continue to license providers on a case-by-case basis. Another option is to begin to enforce increasing levels of participant survivability and/or apply FAR-type regulations derived from past data. Mission assurance activities could further augment these options.

The scope of the regulation needs to include an evaluation of the design of the vehicle along with ground operations, flight operations, testing, training, and maintenance. This will also include characteristics of design and operating margins typically associated with specific subsystems and/or functions. The licensing would include aspects of the Airworthiness, Air Carrier, and Airport Certifications currently issued by the FAA for aircraft. We believe that this approach is consistent with the anticipated state of the industry during early experimental operations, in which a single provider works exclusively with the manufacturer of a single vehicle and operates out of a unique spaceport. As the industry matures, it is anticipated that the service providers will begin to operate multiple airframe types and vehicle manufacturers will supply multiple service providers, thus evolving to a state similar to that of today's commercial aircraft industry. The data collection and evaluation requirements must take into account this evolutionary path by designing modularity (i.e., independent evaluations of vehicle, ground ops, flight ops, etc.) into the evaluation process.

NASA has expressed interest in the use of commercial crew transfer vehicles to support the International Space Station (ISS), under the Commercial Orbital Transportation Services (COTS) program. Per NASA's requirements, the associated launch operations must be licensed by the FAA. However, the FAA's role of licensing should reflect those regulations required by the FAA (as discussed herein) and not necessarily more stringent requirements that NASA may levy on human-carrying spaceflight vehicle operations involving the ISS.

Collection of Design, Test, and Flight Data

In comparison to conventional aircraft, reusable launch vehicles (RLVs) fly over a much larger operational envelope of flight speeds and altitudes. Due to high flight costs, it is not feasible to statistically determine flight safety levels over all operating boundaries by flight test alone. Therefore, the quantification of flight safety levels necessary for launch and reentry licensing will be dependent on a judicious combination of analysis, inference from comparable existing systems and subsystems, ground testing, and flight test and demonstration. Initially, little statistical experience will exist to relate participant safety to the combination of complex robustness decisions (e.g., design margin, degree of testing, escape provisions, concept of operations, etc.). Therefore, the initial methodology would focus on collection of data for individual safety-related parameters. These parameters are intended to cover all phases of flight that may or may not apply to a space plane system as follows: (1) pre-launch, (2) boost/launch or lift by jet or balloon followed by boost/lift, (3) separation/staging, (4) apogee/orbit, (5) reentry, (6) landing, and (7) post-landing.

These representative steps in regulatory evolution may evolve into a very different analytical construct for human spaceflight as industry knowledge increases and an experience base is developed. However, it is instructive to understand the types of data that would be required in later steps, so that proper data can be collected in early steps. Development of this approach emphasizes safety-based metrics (e.g., design margins, performance, qualification, testing, concept of operations, and process/manufacturing quality) rather than traditional design or performance metrics (e.g., engine type, takeoff and landing mode, etc.). Considerations for the human factors (e.g. pilot qualifications, crew training, participant safety training, and related factors) are just as integral to the overall safety process, and must be evaluated alongside the vehicle design and operations factors.

Initial Regulation Alternatives

The traditional role of the FAA has been to certify an aircraft as “safe to fly.” After evaluation of an aircraft’s design margins, CONOPS, ground maintenance procedures, and other factors, the FAA evaluates whether that aircraft meets a minimum set of criteria, and if so, issues certification. This same type of role is envisioned as a goal for the long-term evolution of regulation regarding commercial human spaceflight. However, the FAA analysis for aircraft is built on a large database that correlates individual design and safety parameters to overall vehicle safety. This database, built from several decades of flight experience, is not directly relevant to the environments and flight envelope of commercial human spaceflight. As such, it is critical for the FAA to build up this database as the industry matures, but initial regulations must be created without statistical backing of this experience.

Without sufficient data, defining a minimum set of criteria for human spaceflight service providers is potentially problematic. The relative benefits and tradeoffs associated with specific design choices are not easily comparable. For example, a vehicle with small design margins and a very robust escape/abort system may provide equal or better overall safety than a vehicle with large design margins and no abort capability. This makes identification of clear-cut minimum standards extremely challenging, and would be difficult to defend. As such, it is worth considering what information the FAA can provide prior to the definition of these minimum standards.

Traditionally, the FAA has not attempted to provide the public insight into the relative safety of the operations of one provider over another. All evaluations were performed relative to the minimum criteria, and only the pass/fail evaluation was disseminated to the public (in terms of acceptance or rejection of the license application). Four potential options are identified below; one of which is not recommended as viable:

1) The FAA continues in its current role of providing licensing on a case-by-case basis, without providing additional information to the public.
   Discussion: There is no attempt to assign a grade indicating what level beyond the minimum criteria a provider had achieved, only that it had passed. As such, relative rankings of providers are not possible. This approach is most consistent with past FAA regulation and practices, and the authors consider it to be a viable alternative.
   However, it is possible that the public may interpret licensing as an indication that these vehicles will have safety performance comparable to commercial aircraft. In addition, the public will have no independent basis to evaluate the relative safety of different provider options, and will be dependent on the claims of the providers to evaluate their own safety characteristics. As with gas mileage or automotive safety, without standardized analysis or testing the individual claims of providers may be fully factual yet entirely misleading. Statute and AST regulations require operators to disclose their safety records and inform the crew and spaceflight participants that the U.S. government has not certified the launch vehicle as safe for carrying them.

2) The FAA continues in its current role of providing licensing. Following each application, the FAA disseminates raw data related to all key safety characteristics of a given provider.
   Discussion: This option would provide the public with basic safety information (e.g., design margin, abort system envelope, predicted abort system reliability, number of test flights, etc.). This option does not require the FAA or its agents to make any judgment about the value of

one design approach over another. However, this approach is unlikely to provide useful information, as most of the general public is not sufficiently knowledgeable about the intricacies of space vehicle design and operations. As a result, this approach provides little practical advantage over Option 1 and is not recommended.

3) The FAA continues in its current role of providing licensing. Following each application, the FAA disseminates simplified metrics (e.g., star ratings) related to the safety characteristics of a given provider. Early metrics would include a separate rating for each key safety characteristic. Once these individual metrics can be correlated to a vehicle-level probability of loss of life in a statistically meaningful way, the FAA will disseminate an overall safety rating for each provider.
   Discussion: This approach is the biggest departure from historical FAA practices by providing information about the relative safety features of different providers. Other government agencies perform this role for other forms of transportation, such as the National Highway Traffic Safety Administration (NHTSA) which provides a star rating system that evaluates the crash worthiness of automobiles under different crash situations. Over time, it is envisioned that a minimum overall safety rating would be developed and incorporated into the licensing process, thus achieving a level of regulation similar to what is currently done for commercial airplanes. This provides the public with a meaningful way to compare the relative safety characteristics of potential providers, and make informed decisions about the tradeoff between safety and other services and features of the flight (e.g., cost, overall flight experience, comfort, branding, training, etc.). In other industries, this type of rating has provided motivation to incrementally improve safety characteristics without requiring the government to regulate all aspects of performance.
   If this approach is to be implemented, careful thought must be given to ensure that the FAA does not appear to be picking winners between providers. During initial operations, safety may be one of the most critical factors that the public uses in choosing a spaceflight provider. A published difference in safety characteristics may be interpreted as an endorsement of one provider or approach. An approach to manage the sensitivities of potential providers, along with understanding the political impact of this new role for the FAA, will have to be worked out during the development of the initial regulations.

4) The FAA creates the methodology described above in Option 3, but does not disseminate the results of the evaluation when issuing a license.
   Discussion: The evaluation of specific individual parameters, and correlating these parameters to overall vehicle safety, can provide a solid methodology for determining whether or not a vehicle meets a set of minimum standards for licensing. From the perspective of the general public, the FAA's role of providing licensing would not change, and many of the political sensitivities would no longer be an issue. The option of not disseminating evaluation results might not be viable if results are requested under the Freedom of Information Act (FOIA), unless the information is proprietary.

A detailed discussion of the implementation of Options 3 and 4 can be found in Appendix B. Any of these options could be further augmented with an evolving mission assurance role, as described in Appendix C.

Summary

The study participants believe the above proposed strategy represents a balanced and evolutionary approach that meets the objectives of both providing an acceptable level of public, participant, and crew safety/survivability, while not stifling an emerging industry. The approach includes collecting relevant data over time while refining the analytical toolset, and thus provides a path for increasing insight and regulation as the industry matures and as it becomes increasingly necessary to protect public safety. Furthermore, the strategy should help to inform the consumer regarding safety of the various provider choices, so that they can evaluate safety when selecting a human spaceflight provider/service.

Topic 2
Review the effectiveness of the commercial licensing and permitting regime under chapter 701 of title 49, United States Code, particularly in ensuring the safety of the public and of crew and spaceflight participants during launch, in-space transit, orbit, and reentry, and suggest whether any changes are needed to that chapter

Conclusion: The current license application, application review, and launch monitoring operations are sufficient at the current time. However, it is recommended that FAA/AST continue examining options for safety approval standards for systems and subsystems, as well as mission assurance processes. FAA/AST should also continue to develop and exercise procedures in collaboration with other affected federal agencies for investigation of possible accidents or mishaps. FAA/AST's licensing and regulating authority is presently limited to launch and reentry operations and does not extend to orbital operations. Regulatory legislation for commercial orbital operations should be considered as needed to address expected future commercial orbital ventures.

In an intensive study involving the review of over 500 safety studies grouped into eleven types of subsystem safety factors, the Aerospace Corporation concluded in a 2003 report that safety standards should be addressed on the basis of performance-based guidelines that emphasize design, qualification, and quality assurance. The guidelines were structured in three interrelated "tiers."

- Tier 1 addressed design and operational guidelines for preventing RLV failure. System reliability criteria were developed addressing crew and spaceflight participant safety and survivability approaches, fail-safe design concepts and principles, qualitative and quantitative reliability assessments, and approaches for validating safety critical systems.
- Tier 2 addressed design considerations to protect crew and participants from harsh operational environments, focusing on compartment design.
- Tier 3 addressed design and operational considerations to protect crew and participants in the event the mission is not recoverable, focusing on abort and escape systems.[3]

These guidelines, based on analysis of military aircraft, experimental space planes, space launch vehicles, and commercial aircraft remain valid as a means of providing for crew and participant safety and for safe launch center operations, with nothing having occurred in the intervening years that substantially alters these conclusions.

A number of relevant steps have been taken since the CSLA amendments were enacted in December 2004. These have included the rulemaking process the FAA has undertaken to establish rules for "ensuring the safety of the public and of crew and space flight participants during launch and reentry."

Diversity in approaches for developing reusable space vehicles for human flights

One thing that has changed since the 2003 report is the level of development activity in new launch concepts that can support human suborbital (and eventually orbital) flights on commercial reusable

[3] N. R. Patel, J.C. Martin, R. J. Francis, and R. W. Seibold, *Human Flight Safety Guidelines for Reusable Launch Vehicles*, Final Report, U.S. Department of Transportation Contract DTRS57-99-D-00062, Tasks 2 and 3, Aerospace Corporation Report ATR-2003(5050)-1, July 31, 2003.

launch vehicles. The number of approaches being taken by these entities to develop spaceplanes and suborbital and orbital craft is so large that the licensing process used for commercial and private aircraft – in which the FAA grants general licenses after flight qualification – is not appropriate. There is currently no standardization with regard to the following critical subsystems:

- Environmental control and life support
- Main propulsion and fuels
- Guidance
- Navigation and control
- Avionics and software
- Main structure
- Thermal protection and control
- Health monitoring
- Electrical power
- Mechanical systems
- Flight and crew safety

Standardization of all of these subsystems may not be necessary, but much more commonality of design in flight-proven conditions is needed before general or type licensing would be appropriate for commercial human spaceflight systems. The testing of these various systems must be undertaken through a long-term flight program encompassing all applicable stages of spaceflight, as noted in Topic 1: (1) pre-launch, (2) boost/launch or lift by jet or balloon followed by boost/lift, (3) separation/staging, (4) apogee/orbit, (5) reentry, (6) landing, and (7) post-landing.

In 2004, FAA/AST issued two licenses for specific RLV missions with a pilot on board. Since then, progress has been slower than anticipated since the CSLA amendments were enacted. Sources of delay have included: (1) slower development of spaceports than first projected; (2) trade restrictions imposed by the International Traffic in Arms Regulations (ITAR) that have slowed capitalization of some projects; (3) delays involving spaceplane development and testing; and (4) the summer 2007 industrial accident at Scaled Composites in Mojave, California, which took three lives and seriously injured others during a test of a rocket engine.

Case-by-case licensing

The Government Accountability Office (GAO) recently provided an in-depth assessment of the current regulation of commercial space activities and related safety provisions after extensive interviews with many individuals and organizations. GAO noted that FAA/AST has the authority to issue licenses for launch and reentry operations with humans aboard as well as the operation of spaceports for commercial launches with humans aboard *on a case-by-case basis*. The report also noted that FAA/AST appears to have the flexibility, at a future date, to issue a "safety approval" for a vehicle or a component of a vehicle that would in effect be a type approval that could be used to support multiple licenses.[4]

FAA's current Launch and Reentry Licensing Process involves evaluating applications and, if approved, monitoring through launch, reentry, landing, and post-launch review. More specifically, this process includes:

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[4] Government Accountability Office (GAO), "Commercial Space Launches: FAA Needs Planning and Monitoring to Oversee the Safety of the Emerging Space Tourism Industry," GAO-07-16, October 2006, p. 20.

- Review of the safety of the launch and the proposed launch and reentry paths. This includes an analysis of the reliability and functions of the vehicle, an assessment of the risk and hazards it poses to public property and individuals, and a review of the launch company's policies and practices to demonstrate that the operations "pose no unacceptable threat to the public."
- Review of environmental impacts under the requirements of the National Environmental Policy Act: 42 USC 4332; the Council on Environmental Quality Regulations for Implementing the Procedural Provisions of the National Environment Policy Act, 40 CFR parts 1500-1508; and the FAA's Procedures for Considering Environmental Impacts, FAA Order 1050.1D. (Note: The issuance of a license to launch by FAA/AST is considered to be a major federal action defined under the National Environment Policy Act and thus must meet the requirements noted above.)
- Review of the payload, pilot, and crew, and arrangements for participants.
- Review of the policy implications of a launch.
- Determination of the launch company's insurance liability and/or financial responsibility.
- Monitoring of actual launch operations.
- Consideration of the post-launch review processes.[5]

The GAO report clearly states: "FAA's plan to address these differences through case-by-case evaluations of individual launch license applications is reasonable for an emerging industry with a wide variety of products." In light of the diversity of products and approaches noted earlier, a "case-by-case" approach to safety regulation and licensing is presently the only reasonable way forward unless a decision is made to limit design and process innovation, perhaps undermining future launch and safety system inventions.

"Case-by-case" review processes by the FAA for reusable vehicles are clearly different from licensing for launch of expendable launchers with contrasting designs, insurance requirements, and liability. Similarly, this licensing process is clearly and fundamentally different from the safety qualification of aircraft. This incipient private commercial space industry is many years away from operation under Department of Transportation regulations as common carriers providing passenger services to the public.

Although there can be commonality between expendable and reusable vehicles with regard to safety review and licensing of the vehicle launches and reentries and their facilities, there are additional safety elements that need to apply to reusable launch facilities. In some cases there are elements that are common to the operation of an airport since the initial aspect of the launch may be very much akin to the takeoff of a conventional jet aircraft. However, in other design configurations such as vertical takeoff and vertical landing, the public safety considerations and operating procedures would be quite different. Furthermore, some of the reusable vehicles with winged configurations have much different flight characteristics than more conventional rocket systems. This raises issues of launch range safety control over wider perimeters to the launch site as well as the nature of possible vehicle destruct capabilities and ground control for escape systems.

Establishing exactly where safety regulations with regard to expendable and reusable systems can be parallel and where they might be separate and different is a complex issue. This will be addressed in detail in Topics 3 and 4 in terms of both range safety controls and launch flight operations.

Launch range safety covers many areas. These areas include ground testing and training facilities, hazardous materials storage facilities, launch and landing operations from the ground control perspective, abort controls and operations at the launch range facility, and escape vehicle operations in terms of

[5] GAO, Appendix III.

ground control. Launch flight operations would involve the spaceplane or spacecraft and its safe launch, ascent, descent and landing. All safety operations, including flight operations, should involve the systematic collection of data under a prescribed and standardized reporting system, as described in Topic 1. Such collection of data would cover nominal and successful operations as well as anomalies or mishaps recorded in experimental flight data. Such data could allow the more effective transition from experimental to licensed launch and reentry operations.

Spacecraft that have humans on board need to be treated differently from launch systems without humans. However, craft on a suborbital flights that involve much slower speeds and g-forces could in some circumstances have less stringent regulatory conditions applied than is the case with regard to launch systems going into orbit. Systems such as those being developed under the NASA Commercial Orbital Transportation Services (COTS) program for access to the International Space Station (ISS) may have yet other provisions and regulatory requirements. The answer may very well lie with practical experience over time as case-by-case review and approval is replaced by "type safety approvals" for subsystems and in the longer term even licensing of entire spaceplane vehicles. In short, because of the complexity of systems and subsystems being developed, the establishing of a single set of rules to fit all cases is simply not possible, nor is it likely to be possible in the relatively near term. Case-by-case regulatory provisions for suborbital flights with humans seems to be the only viable way forward for a number of years until actual experience is gained.

Effective U.S. government response to commercial spaceflight mishaps

There are a number of Memoranda of Agreement (MOAs) between the FAA and other agencies, especially NASA and the U.S. Air Force (USAF), with respect to commercial launches. These were developed in the context of expendable commercial launches for commercial payloads and appear to cover launches with humans aboard. These MOAs for the most part seem to cover needed standardization of procedures and processes with regard to range safety needed to govern commercial launches.[6]

Review of these documents, in particular the Memorandum of Understanding (MOU) between the National Transportation Safety Board (NTSB), USAF, and FAA, however, led to consideration of whether further procedures and training processes may be needed to address the case of a commercial launch with humans aboard where an accident with fatalities might occur and especially if the accident could create a major public safety hazard. Lessons in this regard might be learned from the instances of the *Challenger* and *Columbia* accidents as well as from responses to the accident at the Mojave test facilities of Scaled Composites in summer 2007. FAA/AST has also developed procedures that indicate

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[6] Memorandum of Agreement between the Department of Defense, Federal Aviation Administration, and National Aeronautics and Space Administration on Federal Interaction with Launch Site Operators, September 1997
Memorandum of Understanding between the Department of Transportation, Federal Aviation Administration, and National Aeronautics and Space Administration Concerning Future Space Transportation Systems, October 1999
Memorandum of Agreement between the Department of the Air Force and the Federal Aviation Administration on Safety for Space Transportation and Range Activities, January 16, 2001
Memorandum of Agreement between the Department of Commerce, the Federal Aviation Administration, and the Department of the Air Force on a Spacelift Range Commercial Requirements Process, February 2002
Memorandum of Understanding between the National Transportation Safety Board, the Department of the Air Force, and the Federal Aviation Administration Regarding Space Launch Accidents
Memorandum of Understanding between the Air Force Space Command and the Federal Aviation Administration for Resolving Requests for Relief from Common Launch Safety Requirements, August 15, 2005
Memorandum of Agreement between the Department of Air Force and the Federal Aviation Administration on Safety for Space Transportation and Range Activities, September 2007

how expertise from other agencies might be obtained and how the FAA would participate in the event of a mishap involving the loss of human life. FAA/AST has conducted tabletop exercises with NTSB, the Air Force, and FAA Accident Investigation pertaining to ELV mishaps, most recently in January 2007.

The conclusion from this review is that some additional procedures and policies, coupled with additional training exercises, may be usefully implemented. These additional procedures or policies would particularly cover commercial launch operations where spaceflight participants, pilots, and crew are involved. Rather than expanding the number of MOAs with various federal agencies, a new Accident Response Plan might be generated. This document would seek not only to ensure the availability and pre-identification of particular expertise that would be targeted to support recovery from an accident, but also develop training exercises to rehearse how individuals from different organizations would rapidly respond to a commercial spaceflight mishap. A single document that spells out a recovery process would serve as a basis for one or more training exercises. Since the NTSB has responded to many types of transportation related accidents over the years, but has never responded to a commercial space launch, such a rehearsal for such an accident seems a prudent precautionary step. Such an accident would quickly become a high visibility event. Thus, planning and training are essential. Approaches to this task might include the following:

- Updating procedures, in cooperation with the NTSB, to identify and immediately draw needed special expertise from the federal agencies that may be needed in the case of an accident involving commercial launch vehicles with humans aboard and carrying out one or more training exercises to validate and potentially improve these procedures. The NTSB has long experience in investigating aviation, highway, marine, and railroad accidents, but has not previously addressed rocket or spaceplane accidents.
- Creating explicit guidelines as to where, how, and when regulatory oversight actually begins and ends. Appendix H to the current MOU between the NTSB, USAF, and FAA represents a good start in this regard, but should reviewed and updated since this MOU is now four years old and new information is available from the *Columbia* accident response and from other areas. Action in this area might be to accept the definitions used by the launch insurance industry as to what is included or not included in a "launch event" or, after study, adopt a somewhat different and broader definition. The key is to distinguish between "non-launch" industrial accidents under the regulatory control of the U.S. Occupational Safety and Health Administration (OSHA) (and State counterparts) and launch operations under the licensing authority of FAA/AST. There is also a need to ensure that appropriate regulatory expertise is available to the oversight and recovery process. There may be a need to provide special expertise to OSHA in "gray" areas involving transport to the launch pad, balloon ascent systems, or jet aircraft acting as initial staging vehicles.
- Generating a document, updated at frequent intervals (e.g., once a year), that explicitly covers how a launch accident would be addressed in terms of access to needed expertise, special processes unique to launch systems, escape systems, and especially the government's oversight role with regard to destruct commands, etc. The first commercial launch with spaceflight participants and crew aboard that results in a mishap, especially with fatalities, will be a matter of intense public and press coverage. Unless there is a clear-cut accident response and recovery plan in place – *well coordinated and tested* with industry, the federal agencies of relevance and even affected local and state governments – then criticism of poor planning would undoubtedly ensue.

New accident response procedures will need to consider questions such as these:

- Should there be detailed implementation or contingency plans that cover more explicitly the nature and scope of federal agency coordination with regard to mishaps, environmental assessments, and recovery under the National Environmental Policy Act (NEPA), especially involving hypergolic fuels, hazardous materials, or other environmental issues?

- The NTSB does not have experience with commercial rockets with humans aboard. Does the NTSB need to have a special liaison, access to expertise, and special processes as to how it would work with the FAA, NASA, the USAF and possibly other agencies such as the Department of Homeland Security or U.S. Northern Command, OSHA, the Environmental Protection Agency or National Guard WMD Civil Support Teams (in case hazardous materials are involved)? The MOU of September 2004 spells out points of contact between NTSB, FAA, and USAF but does not indicate how specialized expertise would be called into play by other federal agencies that might be required and does not envision any training or coordination exercises. It would be useful to update this MOU to indicate a process whereby expertise from other agencies, such as NASA, might be called into play at any time.
- Should the planning and contingency document consider the public safety, potential environmental impacts and air traffic hazards inside and perhaps even outside of the launch and landing areas? FAA has studied the *Columbia* accident and instituted enhanced air safety controls and aviation protection systems based on this experience. These procedures will be further enhanced based on experimental launch experience. The issue of whether there is to be a destruct capability on certain categories of commercial rockets, controlled by a government Range Safety Officer, needs to be addressed.
- Is there a need to undertake training exercises based on the Accident Response Plan procedures for designated individuals or teams? Examples of training scenarios include a launch accident involving a fuel explosion, a crash landing of a craft or an escape vehicle, and the disbursal of possibly hazardous debris covering a large geographic area.

GAO recommendations on FAA/AST capabilities and safety measures

The GAO report made three specific recommendations, two of which are applicable to this topic and are discussed below.

> **GAO recommendation 1**: As part of its strategic planning effort, FAA needs to assess the level of expertise and resources that will be needed to oversee the safety of the space tourism industry and the new spaceports under various scenarios and timetables. In addition, the Office of Commercial Space Transportation should develop a formal process for consulting with the Office of Aviation Safety about licensing reusable launch vehicles. The process should include the criteria under which the consultation takes place.[7]

FAA/AST has established, after careful study and coordination, due process for reviewing and regulating public safety issues as well as setting reasonable safety controls for pilots, crew, and participants involved in the space tourism and personal spaceflight industry. FAA/AST also is looking ahead to the post-2012 time period when the expansion of private spaceflight activity may include not only suborbital flights with participants but other activities involving humans in space. Examples include: private space stations (such as those planned by Bigelow Aerospace), U.S. commercial space vehicles that provide access to the ISS (such as those resulting from the COTS program), commercial vehicles sanctioned by other governments, and private space research and industrial development in orbit.

Other regulatory issues related to the National Environmental Policy Act, ITAR clearances, and national security will require additional attention. An assessment of the FAA expertise and resource needs

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7 GAO, p. 40.

to address and regulate these expanding activities may be appropriate so that adequate regulatory and safety support can be provided in a timely manner.

> **GAO recommendation 2:** To allow the agency to be proactive about safety, rather than responding only after a fatality or serious incident occurs, FAA should identify and continually monitor space tourism industry safety indicators that might trigger the need to regulate crew and flight participant safety before 2012. As part of this effort, FAA should develop and issue guidance on the circumstances under which it would regulate crew and flight participant safety before 2012.[8]

Experience from aviation, legacy space launch systems, and other high risk industries suggests that proactive steps as well as safety measures and indicators are needed to ensure adequate preparation for mishap response. FAA and the private spaceflight industry must have effective means for sharing information, assessing lessons learned, and developing better safety indicators. Specific plans for mishap investigations and an Accident Response Plan that addresses training and coordination exercises, as noted above, would be appropriate.

Central to the success of this industry is allowing entrepreneurial talent to develop new technologies and systems that are simpler and safer than traditional launch provider systems. The key to doing this with a minimum of government regulation, as described in Topic 1, is the systematic collection of safety statistics and data that can be compiled and documented so that safety progress of vehicles, ground operations, and subsystems across the industry can be monitored without compromising the proprietary information of individual companies.

[8] GAO, pp. 40-41.

Topic 3
Is there a need for commercial ground operations for commercial space flight, including provision of launch support, launch and reentry control, mission control, range operations, and communications and telemetry operations through all phases of flight? If such operations are developed, should they be regulated, and if so, how?

Conclusion: Commercial ground operations are needed and will be largely the responsibility of the launch vehicle operators for the foreseeable future due to the diversity of design concepts. FAA/AST already is laying the groundwork for incorporating commercial spaceflight into the National Airspace System while allowing industry efforts in this area to mature at their own pace.

Ground operations are an essential component of any space launch system. In the particular case of commercial human spaceflight, the important questions are: Should ground systems be owned and/or operated by the government, the private sector, or a combination of both? If a combination of both, what specific functions should each be responsible for? This report has already discussed the diversity of launch vehicle design concepts and the embryonic stage of the commercial human spaceflight industry. These characteristics hinder attempts to define an optimal allocation of responsibilities for mission control, range operations, and other launch and reentry support functions. Respondents to the industry questionnaire overwhelmingly expressed the belief that for the foreseeable future, ground operations will be very system-specific and therefore the responsibility of the vehicle operator.

Recognizing this situation, this section briefly addresses statutory requirements and the establishment of regulatory authority, some of the major elements of government involvement in commercial ground operations, and focuses on the second part of this topic's question, how regulation of ground operations may evolve.

The regulatory actions[9] and planning of FAA/AST already have addressed the operations and safety of ground support. In particular, FAA/AST has developed an excellent concept of operations for integrating commercial space transportation (CST) into the aviation-based National Airspace System (NAS).[10] The treatment of "mission planning" (a more apt label than "mission control") in CST operations clearly provides the desired seamless integration.

Is there a need for government involvement in commercial ground operations?

FAA/AST is authorized to license and regulate U.S. commercial space launch and reentry activities and the operation of non-federal launch and reentry sites. Pertinent sections of the statute (order rearranged) are included below:

Title 49 USC, Section 70101(a): Congress finds that…

> (11) private industry has begun to develop commercial launch vehicles capable of carrying human beings into space, and greater private investment in these efforts will stimulate the Nation's commercial space transportation industry as a whole

9 14 CFR-Astronautics and Space, Chapter III, Commercial Space Transportation, Federal Aviation Administration, Department of Transportation, primarily Parts 417 and 420.

10 Daniel P. Murray (FAA/AST) and Richard VanSuetendael (FAA/ATO-P), "A Tool for Integrating Commercial Space Operations Into The National Airspace System," AIAA Paper 2006-6378, August 2006.

(8) space transportation, including the establishment and operation of launch sites, reentry sites, and complementary facilities, the providing of launch services and reentry services, the establishment of support facilities, and the providing of support services, is an important element of the transportation system of the United States, and in connection with the commerce of the United States there is a need to develop a strong space transportation infrastructure with significant private sector involvement

(10) the goal of safely opening space to the American people and their private commercial, scientific, and cultural enterprises should guide Federal space investments, policies, and regulations[11]

In its approach to this mandate, the FAA/AST has recognized that CST is an embryonic element of the National Transportation System that has the potential to evolve into a major element of that system over time. It also recognizes that this evolution will likely occur over an extended time period. More importantly, it has identified the emerging competition for airspace among NAS users and has made integration of the CST element into the current NAS a priority by developing a Space and Air Traffic Management System (SATMS), which is a conceptual aerospace environment where space and aviation operations are seamless and fully integrated in a modernized, efficient NAS. FAA/AST is supporting the efforts of the Next Generation Air Transportation System (NextGen) Joint Planning and Development Office (established December 12, 2003 in response to FAA reauthorization Vision 100, Public Law 108-176) in developing an integrated national plan for air and space traffic control.

Overall, FAA/AST has more than adequately indentified the need for government involvement in commercial ground operations for CST and is building an appropriate and comprehensive response.

Launch industry evolution

The possible commercial vehicles of the near- and long-term future are described in some detail and compared to existing operational concepts in a recent report.[12] The FAA's approach to covering the full range of potential vehicles, from conventional expendable to partially-reusable to fully-reusable, and encompassing vertical take-off and landing through horizontal take-off and landing and every combination thereof, assures a seamless integration of CST and aviation demands on the available airspace.

The future of space transportation depends on commercial involvement, as did the evolution of the air transport, railroads, and maritime systems. It depends on development of a market for commercial services. Providing a source for government space operations is a well-demonstrated commercial capability that is both economically attractive and sufficient for the near term. Emerging human spaceflight services may provide some impetus in developing a viable industry.[13]

The long-term market lies in both developing and satisfying the commercial business interests for cargo movement in point-to-point operations and providing the general public (always the best source of long-term return on investment) with an affordable adventure or an affordable and faster, or perhaps just more interesting, mode of transportation. For example, there is a growing interest in local lighter-than-air flight and in luxury railroad travel, both of which point to the continuing interest in pleasure travel.

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[11] Title 49 USC-Transportation, Subtitle IX, Commercial Space Transportation.

[12] FAA/AST, "2008 U.S. Commercial Space Transportation Developments and Concepts: Vehicles, Technologies, and Spaceports."

[13] FAA/AST, "Suborbital Reusable Launch Vehicles and Emerging Markets," February 2005.

The National Airspace System

The country's National Airspace System (NAS) is comprised of the entire network of interconnected systems and infrastructures, the people who operate those systems, the vehicle operators who rely on those systems to be operable, and the myriad of operational procedures and processes and certifications. In the United States, the NAS includes tens of thousands of airfields and airports, extensive air traffic control facilities, and a plethora of equipment that operate and interact continuously to keep the NAS operating efficiently and safely.

The NAS is a continually evolving system as dictated by technology enhancement of equipment, improvements in operating procedures and processes, growing airspace demands, and the addition of new flight operations such as CST. For example, the FAA's GPS implementation activities are intended to evolve the NAS infrastructure to accept satellite navigation technology. The implementation process will ensure that each aspect of the NAS infrastructure is addressed and readied for satellite navigation.[14]

Note that generally the NAS has no upper limit. The practical limit is established by the application of the "controlled airspace," which encompasses that volume of air from mean sea level to 60,000 feet in elevation. That includes the airspace overlying the waters within 12 nautical miles of the coasts of the 48 contiguous states and Alaska. Cognizance of operations outside of this region is less clear, which leaves the question of who is going to regulate flight services over the U.S. above the 60,000-foot level as commercial spaceflight grows in the future. And that in turn generates additional questions of international overflight, return from orbit over another country, abort to another country, and which agency or agencies will control and monitor the various vehicles, which may be internationally owned. The FAA continues to re-examine its policy in this area as flight envelopes expand.[15]

Integrated operations

New methods and procedures allow rapid assessment and reconfiguration of airspace structures and traffic. Thus, sector configurations are unconstrained by current boundaries. Dynamic reconfiguration of airspace within and between facilities increases operational flexibility.

In integrating the CST into the NAS, the FAA has defined two concepts that support the integration task:

- *Space Transition Corridors* (STCs) provide dynamically reserved and released airspace in the NAS for space vehicles launched from spaceports to fly over populated areas and through commercial airways to reach orbit or achieve suborbital trajectories. STCs are selected and determined based on performance characteristics of the vehicle and overall safety considerations. STCs may be tailored as mission needs or ATC needs dictate, and provide more flexibility than today's special-use airspace (SUA).
- *Flexible Spaceways* similar to today's airways and jet routes serve traffic transitioning to and from space. These are dynamically designated to meet specific mission objectives, such as transitioning to airborne launch points, aerial refueling, etc. Depending on the mission and vehicle profile, spaceways may be used in conjunction with an STC, to

14 FAA Joint Planning and Development Office (JPDO), "Concept of Operations for the Next Generation Air Transportation System (NextGen)."

15 FAA/AST, "Concept of Operations for Commercial Space Transportation in the National Air Space System, Narrative, Version 2.0."

segregate different types of missions, to concurrently accommodate different mission phases (e.g., launches vs. reentries), and to ensure safety in case of contingencies.[16]

The current regulatory framework

A review of current air transport regulations on the support and operation of human/cargo spaceflight systems suggests that these current regulations and associated guidelines are directly applicable to and adequate to support the CST operations. To that end Congress directed the FAA to adopt an active role in CST and authorized the FAA:

- to directly support the CST: "…to promote public-private partnerships involving the United States Government, State governments, and the private sector to build, expand, modernize, or operate a space launch and reentry infrastructure." [Title 49 USC Section 70103 (b)]

- to regulate the CST: "(13) a critical area of responsibility for the Department of Transportation is to regulate the operations and safety of the emerging commercial human space flight industry" [Title 49 USC, Section 70101]

- but to regulate with due caution and consideration: "(15) the regulatory standards governing human space flight must evolve as the industry matures so that regulations neither stifle technology development nor expose crew or space flight participants to avoidable risks as the public comes to expect greater safety for crew and space flight participants from the industry." [Title 49 USC, Section 70101]

The need for further regulation will emerge as the Concept of Operations is being implemented principally to provide the mechanism to fully integrate aviation and commercial space into the same airspace. For the most part, near-term requirements may be satisfied by modifying appropriate sections of 14 CFR to explicitly incorporate the operating procedures and processes of the Concept of Operations. Subsequent regulatory needs will evolve as operating experience, technology enhancement, and industry growth necessitate, possibly applying the principles and approach proposed in the Topic 1 discussion.

Launch range safety regulation

Launch range safety experience for various types of vehicles, including protection of public safety, is now more than 50 years old. A great deal of knowledge has been acquired about how to prevent accidents that could harm launch support crews and the uninvolved public. In short, much more is known about safety on the ground than is known about human spaceflight, especially its commercial variety.[17]

NASA and the U.S. Air Force have well-developed procedures for range safety, which form the basis of the criteria for commercial human spaceflight. Commercial satellite launches from the Eastern and Western Test Ranges (ETR, WTR) have to abide by the same range safety criteria as older, government owned and operated vehicles. Launches of new vehicles also are subject to the same safety criteria.

One of the most important safety responsibilities of the range commanders (i.e., the commanders

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16 FAA/AST, Space and Traffic Management System, "Addendum 1: Operational Description to the Concept of Operations for Commercial Space Transportation in the National Air Space System, Narrative, Version 2.0"

17 National Research Council, Aeronautics and Space Engineering Board, Committee on Space Launch Range Safety, "Streamlining Space Launch Range Safety" (National Academies Press, 2000).

of the United States Air Force Space Command's 30th Space Wing at Vandenberg AFB, CA, and 45th Space Wing at Patrick AFB and Cape Canaveral AFS, FL) is to ensure public safety during launch and flight. Range safety personnel evaluate vehicle design, manufacture, and installation prior to launch; monitor vehicle and environmental conditions during countdown; monitor the track of vehicles during flight; and, if necessary, terminate the flight of malfunctioning vehicles. The method used for flight termination depends on the vehicle, the stage of flight, and other circumstances of the failure. In all cases, propulsion is terminated. In addition, the vehicle may be destroyed to disperse propellants before surface impact, or it may be kept intact to minimize the dispersion of solid debris. Flight termination can also be initiated automatically by a break-wire or lanyard pull on the vehicle if there is a premature stage separation.

Current flight termination practices have an excellent safety record. From 1988 through November 1999 there were 427 launches at the ETR, during which 11 destruct commands were issued [two Atlas 2, one Delta 3, one Titan 4, four Trident submarine-launched ballistic missiles, and three other missiles]. Over the same time period there were 177 launches at the WTR, during which 11 destruct commands were sent [one Athena, two Pegasus, one Titan IV, and seven intercontinental ballistic missiles]. Total failure of a flight termination system (FTS) is extremely rare at either range, and destruct commands are often superfluous because vehicles explode or break up because of dynamic forces before the mission flight control officer can react.[18]

From a range safety standpoint, reusable vehicles (i.e., the space shuttle) are presently subject to the same constraints as expendable vehicles. The fact that a launcher is carrying humans does not lessen range safety constraints. The space shuttle has a launch FTS on the solid rocket boosters (SRBs), which was activated after the breakup of the *Challenger* stack in January 1986. Each time the shuttle is launched at Cape Canaveral, an Air Force range safety officer monitors events during the first two minutes. If the spaceship should veer off course and endanger a populated area, this officer would have the responsibility of flipping a pair of switches on a flight termination control panel (Figure 1). The first switch arms explosives on the shuttle's two solid rocket boosters. Flipping the second switch would detonate them, destroying the shuttle and crew. The shuttle has no FTS capability for reentry operations.

Figure 1. Space Shuttle Flight Termination System Control Panel (Reprinted courtesy of NASA)

Critical aspects of traditional range safety philosophy, which relate to commercial human spaceflight plans involving privately developed and operated spaceports, are as follows:

- Present conventional rockets carry a large amount of explosive propellants, with the potential to cause extensive property damage and loss of life if they land in populated areas. Certain developmental RLVs use hybrid propellants, such as nitrous oxide (N_2O)/ hydroxyl-terminated polybutadiene, which can decrease but not eliminate explosive potential upon impact.
- Rocket trajectories must be monitored during launch to ensure that they do not impose an undue hazard to populated areas. The FAA's reviews of license applications for spaceport facilities require launch trajectories that result in acceptable casualty expectation (Ec) analyses for flights over or near populated areas.

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[18] Future Interagency Range and Spaceport Technologies, Interagency Working Group of the FAA, DoD, and NASA, "Space Vehicle Operators Concept of Operations: A Vision To Transform Ground and Launch Operations."

- Present standard practice for launch vehicles having sufficient propellant to cause extensive ground damage is to equip them with FTSs, operable by ground personnel, to allow timely independent response in the event of loss of guidance or control which could cause the vehicle trajectory to deviate in such a way as to threaten populated areas.
- Range safety and launch FTSs are the responsibility of the range operator (USAF for the Eastern and Western Test Ranges and NASA for the Wallops Flight Facility). Range Safety is an independent operation, and Range Safety Officers are not responsible to the launcher or the payload organizations.[19]

The requirement for an independent range safety office and an FTS does not apply to airplanes. Despite the fact that airplanes carry large amounts of fuel and can cause extensive damage if they crash into populated areas, the governing principle is that with a human pilot on board (two pilots for large airplanes), loss of guidance or controllability is unlikely and precludes the need for an FTS. Also, airplanes move much slower than rockets, and air traffic controllers can detect potentially threatening situations and alert military resources in time to deal with a developing situation (at least in principle). The presence of a pilot or pilots on a number of planned developmental RLVs brings their flight operations closer to those for conventional aircraft.

Alternate flight safety systems are being tested for commercial RLVs under development. Examples include thrust termination systems (TTSs), which end the propelled stage of flight. These systems can be controlled by humans in line-of-sight or monitoring a computer screen, to prevent the rocket from leaving the designated fly zone. They can also be triggered by valves within the vehicle that terminate the thrust should the propellant pressure increase or decrease to a value outside specified safety parameters. Other safety systems include autolanding systems and the ability to switch from horizontal flight to angling downward for controlling the flight path. Some small sounding rockets are not required to have FTSs or TTSs. Sounding rockets are generally spin stabilized, meaning that active guidance is not required; hence the probability of loss of control taking a rocket out of the test range is extremely small.

Where in this risk spectrum will future commercial human space vehicles fall? This is still to be determined and varies greatly based on the wide range of designs currently being pursued. Some systems such as XCOR's *Lynx* rocketplane will operate much like a jet aircraft and will be piloted much like a aircraft during takeoff and landing. Other systems such as Blue Origin's *New Shepard* and Armadillo Aerospace's *Black Armadillo* (as currently designed) will take off vertically and land with vertical stabilizing thrusters like a spacecraft. Many other designs are also being pursued as previously discussed. In short, no systematic and unified set of controls for launch range safety can be applied at this time because of the great diversity of designs for space systems.

Each potential launch system seeking a license undergoes an analysis to determine the maximum probable loss in the case of loss of control, as has been done for all existing launch vehicles. The risk analysis needs to include the size of the protected range and potential inhabited regions near the perimeter. This is why there is a preference for launch facilities to be located in isolated areas or on seacoasts.

Different systems and different launch sites will have different damage potentials. Also, a hazard analysis must be conducted to determine scenarios that could lead to loss of control. Systems using an aircraft or balloon as a first stage would presumably have very different risks early in flight than those using more traditional vertical take-off rockets. During the reentry portion of the flight, the vehicle will

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[19] Daniel P. Murray (FAA/AST) & Robert E. Ellis (FAA Air Traffic Organization, Fort Worth Air Route Traffic Control Center), "Air Traffic Considerations for Future Spaceports," 2nd International Association for the Advancement of Space Safety (IAASS) Conference, Chicago, May 14-16, 2007. .

presumably not be carrying large quantities of propellant, so the potential hazards diminish but do not disappear. FAA/AST takes these issues into account when issuing permits and licenses.

There may be commercial human spaceflight vehicle configurations with sufficient risk that a FTS or TTS should be required. This is not something that can be determined at this time, but designers of future commercial human launch systems should be aware of the possibility. The presence of a FTS or TTS might seriously impair the commercial viability of a company's launcher, so it is important to establish range safety criteria well enough in advance to be of use to designers and operators. New techniques for range safety, including autonomous FTSs based on GPS, have been under study for several years.[20] The USAF Space Command is considering switching to GPS satellite-based tracking and use of more automated destruct capabilities for vehicles that veer off course. There are plans to add these capabilities to the Evolved Expendable Launch Vehicle (EELV) Atlas 5 and Delta 4 rockets. This is an area where standardized equipment would be of great benefit to the emerging commercial human spaceflight industry.

Assignment of responsibility for range safety operations is a crucial question. As mentioned above, for government launches, range safety is the responsibility of the range operator. The Wallops Flight Facility (WFF) has formed a partnership with the Virginia Commercial Space Flight Authority to deal with these issues at WFF.[21] The FAA licenses commercial launches, including future human launches, and the licensee is responsible for human safety. However, range safety for any launches from existing government launch facilities will almost certainly remain the responsibility of the USAF or NASA.

Part 417 of 14 CFR addresses range safety requirements for launches from both federal and non-federal sites. The required activities fall into three general categories:

- Determination of range safety requirements for different launch vehicle configurations.
- Determination of the type of range safety FTSs or TTSs that should be used, if required.
- Operational management of range safety once flight activities start.

Part 431.43 of 14 CFR requires that an applicant for RLV mission safety approval submit procedures for:

1. monitoring and verifying the status of RLV safety-critical systems sufficiently before enabling both launch and reentry flight to ensure public safety and during mission flight (unless technically infeasible), and
2. human activation or initiation of a flight safety system that safely aborts the launch of an RLV if the vehicle is not operating within approved mission parameters and the vehicle poses risk to public health and safety and the safety of property in excess of acceptable flight risk.

Part 431.43 also specifies that any RLV that enters Earth orbit may only be operated such that the vehicle operator is able to:

1. monitor and verify the status of safety-critical systems before enabling reentry flight to assure the vehicle can reenter safely to Earth; and
2. issue a command enabling reentry flight of the vehicle. Reentry flight cannot be initiated autonomously under nominal circumstances without prior enablement.

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[20] J. S. Leung, G. L. Fay, II, T. A. Patrick, S. L. Osburn, & R. W. Seibold, "Space-Based Navigation for RLVs and ELVs," Final Report, U. S. Department of Transportation Contract DTRS57-99-D-00062, Task 16, Aerospace Corporation Technical Report. No. ATR-2006(5200)-1, February 8, 2006.

[21] Bruce Underwood, Steven Kremer, & Wayne Woodhams, "NASA's Wallops Flight Facility Rapid Responsive Range Operations Initiative," AIAA 2nd Responsive Space Conference, April 2004.

Part 437.67 of 14 CFR requires that applicants for experimental permits track reusable suborbital rockets. Specifically, a permittee must:

1. during permitted flight, measure in real time the position and velocity of its reusable suborbital rocket, and
2. provide position and velocity data to the FAA for post-flight use.

As mentioned above, determination of range safety requirements should be a near-term, high-priority activity. This has a potentially significant impact on launch system design; these requirements should be available to start-up launch companies early in the design process. At this time, much national expertise in range safety resides in the current range operators, although the FAA has developed its own safety expertise. The FAA should continue to draw upon this expertise at least for initial range safety considerations. Eventually, the FAA will need to determine whether it should develop its own internal range safety expertise or continue to rely on other organizations. This decision will in part depend on the willingness of the USAF and/or NASA to become involved with range safety at private spaceports over the long run.

The licensees are ultimately responsible for public safety in cases where private spaceport operators provide range safety operations. This poses a potential issue for the independence of the public safety function. As noted above, the USAF or NASA has the responsibility for range safety for the ranges that each organization operates. The range safety officer has no programmatic connection with or responsibility for the organization launching a payload. Also, the range operators are not trying to turn a profit from their launch operations. In contrast, the commercial success of a private spaceport will depend on the number of customers that can be attracted to use the facility. Minimizing the cost of meeting range safety constraints will increase the commercial attractiveness of a spaceport. This of course remains true only up until the time when an accident occurs and then the reverse conclusion quickly applies.

A guiding principle for safety within large organizations is that the safety division must operate independently of operational programs. (The incorporation of safety functions into line program organizations at NASA was cited as an important factor in the *Columbia* accident report in weakening NASA's safety culture.) Safety personnel must answer to independent management, not to the programs whose safety they are responsible for. Ensuring adequate separation of interests will be a significant problem if range safety is the responsibility of the same organization that is attempting to make a profit from spaceport operations.

Summary

The questions posed for this topic are being answered by the regulatory actions and planning of the FAA. Congress has demonstrated that it recognizes a need for government involvement in the CST system and has provided direction and authority to the Department of Transportation under Title 49. Congress constrained the regulatory process with this language: "… the regulatory standards governing human spaceflight must evolve as the industry matures…[so as not] to stifle technology." The FAA has met that constraint as presented in Concept of Operations reports by absorbing the CST into the NAS rather than develop an entirely separate system. What remains to be done is to incorporate the Concept of Operations into 49 USC and 14 CFR to accommodate the current state of CST and, in an evolutionary manner, enact further regulatory changes and strictures as needed in the future.

Topic 4
Should expendable and reusable launch and reentry vehicles be regulated differently from each other, and should either of those vehicle types be regulated differently when carrying human beings?

Conclusion: Launch of expendable vehicles, when used as a first stage to lift reusable rockets carrying crew and spaceflight participants (passengers), as well as launch and reentry of reusable launch vehicles with crew and spaceflight participants aboard, should be regulated differently than launch of expendable vehicles without humans aboard. Range safety controls, regulation, and licensing may have substantial areas of commonality regardless of whether the vehicle is expendable or reusable or has humans aboard. Current range safety processes can continue to apply, with pertinent upgrades as needed. Until more experience is gained with commercial private spaceflight vehicles, however, the regulation of expendable and reusable vehicles for launching humans should remain on a case-by-case basis under existing FAA/AST rule-making, due to the great diversity of vehicle design, system components, and flight characteristics. The development of a metadata system, as recommended under Topic 1, to monitor the development and actual performance of commercial launch systems and to better identify different launch risk factors and criteria, would assist greatly in the regulatory process.

Space launches using either expendable or reusable vehicles are complex operations that require careful technological planning and oversight at all levels of preparation, launch operations, and landing. Various issues relating to diverse vehicles are addressed separately to avoid providing overly generalized answers.

Flight vehicle and flight operations characteristics

An examination of four categories of current and proposed vehicles and operating modes reveals a lack of common characteristics that would suggest a preference for common regulatory approaches. The vehicle categories that were considered are discussed below.

- <u>Fully Expendable (no components returned)</u>. This is the classic launch vehicle, designed to function only once to deliver a payload (science experiment, satellite, etc.) into orbit, for a landing on another planet, for long-range space exploration, etc. The launch vehicle ignites and lifts off, shedding stages, fairings, and assorted other parts, generally into the ocean but sometimes on land, as its travels to its ultimate delivery point. It spends a minimum amount of time in the National Airspace System and generally is autonomous. The vehicles fly in constrained, well defined vertical columns in the NAS.
- <u>Partially Expendable (some components returned)</u>. This is essentially the same as above with the exception that the payload and various other parts may be recoverable and reusable. Historical examples are the CORONA class of satellites used for reconnaissance operations (film returned to Earth) and the Mercury, Gemini, and Apollo manned space programs (people returned to Earth). These vehicles were generally the same as fully expendable vehicles except for spending considerable more time in the NAS, both on launch and return to Earth, and in the case of the manned programs, having a crew on board that could fully or partially control flight (John Glenn on Freedom 7, Neil Armstrong on Gemini 8, responding to a stuck altitude control system valve, and Neil Armstrong again during the Apollo 11 landing).
- <u>Partially Reusable</u>. The prime example here is the Space Transportation System, which is reusable to the extent of returning the solid boosters and the fly-back Orbiter Vehicle. The Pegasus flight system also belongs in this class to the extent that the carrier vehicle is reused.

These concepts spend considerably more time in the NAS but fly in a mix of column and horizontal box flight patterns.

- Fully Reusable. This group represents "future space," though two examples have flown, and one (Virgin Galactic/Scaled Composites *SpaceShipTwo*) is anticipated to be introduced into the marketplace in the relatively near future. In this instance the vehicle is intended to be reused in its entirety and, of the various concepts, has the longest loiter time in the NAS. Generally, these vehicles fly in a box/column flight pattern.

The above variations in vehicle designs and flight characteristics are substantial and do not realistically allow regulation simply on the basis of "expendable" or "reusable" categorization. The primary purpose of regulatory activity under the CSLA is to promote and protect the safety of (1) the public and public infrastructure, (2) the other users of the NAS, and (3) the participants and crew of the commercial space transporter. Fundamentally the regulatory process should address the need to protect the above and should be based on enhancing the safety of operations in those areas that affect this need.

A logical approach to this regulation is in terms of interaction with Concepts of Operations (CONOPS) for integrating commercial space travel and civil/commercial aviation. Such CONOPS will accommodate future commercial space operations within the NAS and provide for the additional safety considerations associated with space vehicles operating in close proximity to air traffic. This approach captures the areas of potential impact of the flight vehicle on the public, NAS users, and participants and crew, rather than focusing on divergent flight vehicle characteristics.

As to whether either or any of these vehicle types should be regulated differently when carrying human beings, the answer is unequivocal. There are a number of systems and subsystems that must be provided to assure an acceptable high level of safety for flights with crew and/or participants that are not required for flights without humans aboard. There is a definite need for specific regulation of commercial human spaceflight to assure the maximum level of safety possible for crew and/or participants is achieved.

Flight operation regulations for different types of launch systems

There are a large number of safety factors related to the launch of expendable vehicles, but even more stringent requirements are needed for reusable and reentry launch systems with humans aboard as well as for expendable vehicles that are employed to launch a reusable craft with spaceflight participants.[22] These standards and their verification may be the responsibility of separate commercial enterprises, newly constituted entities from the launch insurance industry, or some other independent agency. These standards and their verification could also remain with the U.S. government.

Although there could be a case where there are reusable vehicles that are flown with robotic controls without humans aboard, this would seem to require the same degree of safety regulation and stringent safety standards to protect the public during reentry and landing operations as discussed previously. Regulatory planners can expect that there will be a number of launch configurations in which an expendable vehicle is used to insert a reusable vehicle into orbit that would later reenter and land. In this case the expendable vehicle would also be subject to more stringent safety standards. In the case of a private operation, safety inspections and safety standards enforcement would be conducted either by independent experts, government inspectors, or both. The responsibility for the standards, inspections, licensing and oversight should be clearly established before these events occur. NASA's Commercial Orbital Transportation Services (COTS) program, whereby contractor companies would provide access to

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[22] Joseph Pelton, John Logsdon, David Smith, Peter MacDoran, and Phillip Caughran, *Space Safety: Vulnerabilities and Risk Reduction in U.S. Space Flight Programs*, Washington, DC, 2005.

the International Space Station (ISS) or private orbital facilities, could provide the first test case and thus a decision as to whether the U.S. government or qualified independent entities would perform these functions.

In the case of reusable vehicles involving the launch and reentry of humans, there should be clearly established oversight and licensing processes that consider performance standards, performance margins, standards verification, as well as processes that pertain to the granting of waivers to those standards. For reasons explained below, somewhat different standards, different licensing and inspection procedures, and different processes and/or authority for granting of waivers, however, would appear appropriate for reusable vehicles making suborbital flights. This is in contrast to reusable vehicles actually going into orbit and de-orbiting since such vehicles involve much more demanding technical performance requirements.

The very different performance characteristics of suborbital and orbital launchers illustrate why this difference in regulatory approach is appropriate. In simplistic terms, reusable suborbital craft that operate much like experimental high altitude jet aircraft should be regulated differently than reusable launch systems that go into orbit and have much more demanding performance characteristics. The key public safety question that applies to both types of craft, however, is whether such commercial reusable spaceflight vehicles should require both mandatory escape capabilities and a destruct capability that could operate from the range safety facility. These questions require more study by the FAA as the relevant technologies and safety systems mature.

Factors common to both expendable and reusable vehicles are general risk management techniques, independent validation and verification, the perceived need for oversight of launch safety as exercised by U.S. government regulatory procedures, and any state or local oversight requirements that may apply, especially as exercised at the launch facility and environs. These also may be common for the safety inspection and oversight activities exercised by insurers of the launch, and the safety precautions and due diligence exercised by the operators of the commercial launch. The inspection by the U.S. government and due diligence with regard to meeting international requirements to minimize orbital debris would also be the same. Another area requiring further study is the degree to which there should be oversight of launch training facilities against clearly established standards.

Despite these similarities and common risk management techniques, it is believed that separate procedures need to apply to reusable launch vehicles, especially those with humans aboard. Nevertheless, the presence of humans is only one factor. Other factors and considerations include: orbital flight versus suborbital flight, lower g forces (3 to 6 gs for short duration) versus much higher g forces of longer duration, different environmental conditions with regard to radiation exposure, orbital debris exposure, much different temperature differentials during reentry and landing operations, different abort and escape options, etc. The lack of the commonality in these various safety factors at this stage suggest that personal commercial space flight is something that needs to continue to be regulated on a case-by-case basis.

A case-by-case approach does not imply a lack of stringent safety regulation. Nevertheless, during the experimental period, elements of risk must be considered part of the process. Historically, human spaceflight has resulted in about a four percent fatality rate for those that have flown (factoring in the multiple missions of some astronauts) and approximately a one percent probability of fatality per flight.[23] Spaceflight accidents are the result of a number of factors:

- Hardware failures despite testing and independent validation and verification.

[23] Stephen Newman, Vice President, ARES Corporation, and former NASA Employee in the Office of Safety and Mission Assurance, briefing at Reach to Space Conference, George Washington University, Nov. 12, 2007.

- Software errors that go undetected in testing.
- Operators errors despite careful training and simulations.
- Complex system designs that reveal flaws under stress conditions.
- Errors in manufacturing, production, assembly, and testing.

Each commercial human spaceflight project now underway is seeking to develop capabilities that are reliable, cost effective, quickly serviced for reuse and, most importantly, safe. The diversity of approaches and innovation prevalent in commercial enterprise is thought by many within the industry to being key to achieving the breakthroughs in safety and practicality needed for these efforts to succeed over the long term. The great diversity of approaches was discussed under Topic 2, and Figure 2 below displays five of the technical concepts now being pursued. Any attempt to narrow the designs of the vehicles toward one or a few approaches at this stage would hinder innovation. The best path forward to a truly safe and practical spaceplane for suborbital flights is still to be determined. In this regard the historical parallel to the early days of aviation seems compelling. Commercialization of airmail and development of the Ford Trimotor, coupled with the Guggenheim Model Airline project, resulted in the testing of dozens of designs before airplanes capable of transporting commercial passengers, and concomitant safety standards, evolved.

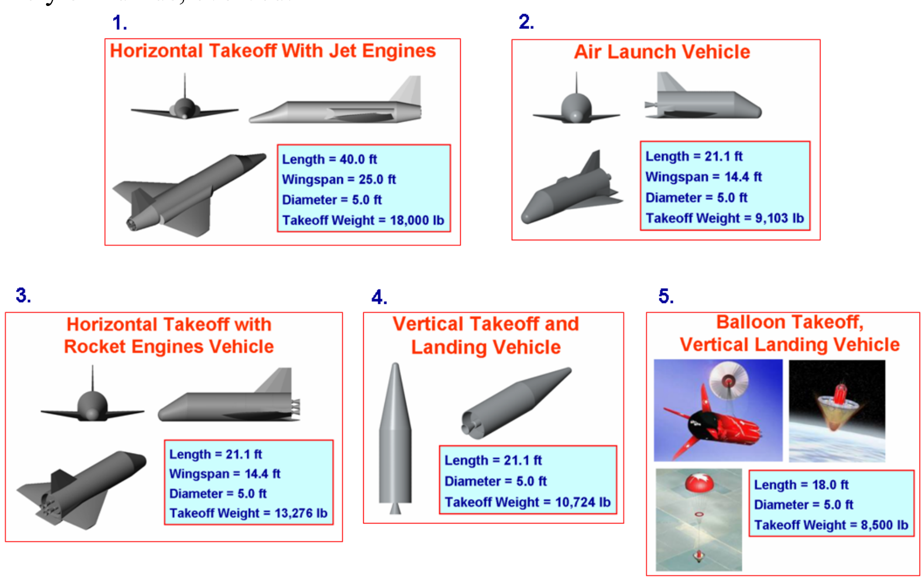

Figure 2. Generic Examples of RLVs Designed for Human Spaceflight

Different types of vehicles are evolving to serve different missions. There are suborbital flights (i.e., sounding rockets) without humans aboard for experimental flights; suborbital flights with humans; orbital and Earth-escape flights without humans aboard, some of which have return capability; and reusable orbital systems that have return and escape capabilities. Each of these has separate safety risk factors and will require different regulatory oversight. The table below notes the differences between reusable orbital launch systems and suborbital spaceplanes.

Building a regulatory regime to systematically oversee the safety of commercial launch systems and more clearly understand the risk factors would be significantly aided by collection and analysis of safety and performance information using metadata[24] categories developed by FAA and industry. This

[24] Metadata is data that describes a data set. Examples include the parameters of a digital image (such as time, date, coordinates, viewing angle, pixel resolution) or the catalog of a library.

data collection is critical regardless of which kinds of vehicles are developed and require U.S. government regulatory oversight. The data would be equally valuable to independent organizations that may be officially licensed to perform this function.

Table 1 Comparison of Reusable Orbital Launch Systems and Suborbital Spaceplane Systems for Human Spaceflight		
Characteristics	**Reusable Orbital Launch System**	**Suborbital Spaceplanes**
Maximum velocities	Up to Mach 25	Mach 4 to 6
G forces	High g forces	3 to 5 g (during descent)
Thermal gradients on reentry	Thousands of degrees C	Hundreds of degrees C
Environmental protection systems and structural strength of vehicle	Very demanding in terms of design and materials	Much lower demands in terms of structural strength, atmospheric systems, life support, etc.
Exposure to radiation	Can be high levels	Minimal exposure due to short flight duration and lower altitudes
Exposure to potential orbital debris collisions	Exposure increases as length of mission increases	Exposure risk is very low due to short duration and lower altitudes
Escape systems	Parts of the flight during high thermal gradients make escape systems extremely difficult and expensive to design	Escape systems are much easier to design due to lower thermal gradients, lower altitude, etc.
Type of flight suits required	Expensive and complex flight suits required	Simple and lower cost flight suits are required due to lower altitudes, lower thermal gradients, much shorter exposure to low oxygen atmosphere
Launch risk factors (overall)	Very high	Considerably lower and different

Exact determination of risk factors associated with different types of launch systems for different types of missions is a complex undertaking. The clear determination of risk factors will only emerge over time as experience is gained. This activity will involve the personal spaceflight industry, other professional aerospace groups, U.S. government employees, and the launch insurance industry. A precise assessment of those risks is years away and cannot be improved until experience is obtained. One model would be for the insurance industry to assume a major role in setting safety and performance standards for the private spaceflight industry in parallel with U.S. government regulatory oversight. Professional aerospace organizations such as the International Association for the Advancement of Space Safety, the International Academy of Astronautics, the American Institute of Aeronautics and Astronautics, and independent third party firms with expertise in space safety can and should assist in this process. This is discussed in more detail under Topics 6 and 7.

The above discussion does not take into account the lack of integrated national and international space traffic management systems, or a precise system for interface between aviation traffic control and space traffic control systems. This is an area that the FAA has addressed with greater concern and interest in the wake of the *Challenger* and *Columbia* accidents. There was a substantial risk of aircraft being hit, damaged, or destroyed in the wake of the *Columbia* accident.[25] The FAA has now put in place a system of alerting and clearing aircraft from danger zones in the event of an accident involving a spacecraft returning from orbit. This is a different type of risk than is posed by a suborbital flight in which vertical ascent is followed by a parabolic arc and then descent within a much more contained flight path. Nevertheless, continued attention needs to be given to this type of aviation-space traffic control issue.

No additional regulatory authority appears to be needed, but national and international standards to address such issues would be desirable, as well as explicit understandings between the FAA, NASA, and the U.S. Air Force about how space and aviation traffic control will be addressed.

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[25] Ibid.

Topic 5
Should the federal government separate the promotion of human spaceflight from the regulation of such activity?

Conclusion: There is no compelling reason to remove promotional responsibilities from FAA/AST at this time. The office is performing these duties adequately and has not yet encountered any conflicts of interest or received complaints on this issue.

The U.S. government promotes private-sector industries for many reasons. Among those applicable to this case, specific industries may be targeted because: 1) the industry needs the endorsement of the government for validation of its legitimacy; and 2) success of the industry will result in significant positive contributions to the U.S. economy and the public interest.

Commercial human spaceflight is an emerging industry with the potential to yield economic benefits to the nation, but its inherent hazards to participants and the uninvolved public require regulation by the government. The Ronald Reagan administration recognized the need for both regulation and promotion of commercial space launch activities for expendable launch vehicles (ELVs) in 1984 in Executive Order 12465, which directed the Department of Transportation to "promote and encourage commercial ELV operations in the same manner that other private United States commercial enterprises are promoted by United States agencies."[26]

In the same year, the Congress also mandated both regulation and promotion of commercial ELVs in the Commercial Space Launch Act (CSLA) of 1984. Since then, the CSLA has been amended to incorporate the launch and return of spaceflight participants. The statute directs the Secretary of Transportation to:

- encourage, facilitate, and promote commercial space launches and reentries by the private sector, including those involving space flight participants;
- take actions to facilitate private sector involvement in commercial space transportation activity, and to promote public-private partnerships involving the United States Government, State governments, and the private sector to build, expand, modernize, or operate a space launch and reentry infrastructure;
- encourage, facilitate, and promote the continuous improvement of the safety of launch vehicles designed to carry humans, and… promulgate regulations to carry out this subsection.[27]

Regulation and promotion of commercial spaceflight have been dual responsibilities of the same federal agency for over two decades. This section will assess whether this arrangement remains appropriate considering the evolution of the commercial space launch industry. It will also consider the experiences of other industries, particularly commercial aviation.

How is FAA promoting the commercial space launch industry?

FAA/AST promotes commercial space launch in the sense that it attempts to facilitate the success of the industry as a whole, mainly through safety measures that boost public confidence. It does not advertise or market on behalf of the industry or individual companies, although it does encourage other

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[26] Ronald Reagan, Executive Order 12465: "Commercial Expendable Launch Vehicle Activities," 49 F.R. 7211, Sec. 2 (b), (c), & (d), February 24, 1984.

[27] Commercial Space Launch Act (CSLA), as amended, Title 49 USC Sec. 70103 (b)(1) & (2).

U.S. government agencies to use commercial launch services in place of government-operated systems whenever feasible.

To establish a clear division of responsibilities within FAA/AST, promotion objectives are managed by the Space Systems Development Division (AST-100), while public safety objectives are managed by the Licensing and Safety (AST-200) and Systems Engineering and Training (AST-300) organizations. FAA/AST estimates that its FY08 resource allocation for activities that encourage, facilitate, and promote the commercial space transportation industry is approximately 16% of the budget, significantly less than what is allocated for activities directly related to safety. It is expected that the current allocation percentage will remain fairly constant for the next few years.

Listed below are some activities that FAA/AST considers to be promotional in nature, although they serve other functions as well.

- Sponsor the annual Commercial Space Transportation Conference, which brings together industry players and other interested parties to share ideas and discuss issues.
- Publish reports and studies, including quarterly and yearly launch summaries, launch forecasts, and a variety of special reports.
- Maintain consultations with industry through the Commercial Space Transportation Advisory Committee (COMSTAC) and its working groups.
- Conduct outreach to potential license applicants.

Responsibilities of the FAA Office of Commercial Space Transportation

http://www.faa.gov/about/office_org/headquarters_offices/ast/about/

- Regulates the commercial space transportation industry, to ensure compliance with international obligations of the United States and to protect the public health and safety, safety of property, and national security and foreign policy interests of the United States;
- **Encourages, facilitates, and promotes** commercial space launches and reentries by the private sector;
- Recommends appropriate changes in Federal statutes, treaties, regulations, policies, plans, and procedures; and
- Facilitates the strengthening and expansion of the United States space transportation infrastructure.

FAA/AST's mandate to encourage, facilitate, and promote the industry results in an array of tasks that can be interpreted differently by various observers. For example, the office works in conjunction with FAA's Joint Planning and Development Office to ensure that future space traffic is considered in the Next Generation Air Transportation System. Also, the office has sought to streamline the review process required under the National Environmental Policy Act. Clearly, these actions go beyond licensing, regulation, and compliance monitoring – they "facilitate" the industry. However, this does not fall under a definition of industry promotion and there is no evidence that the FAA has endangered or interfered with the safety of flight operations in its role as a regulatory ombudsman.

In response to questions posed by the authors of this study, FAA/AST suggested that these activities complement each other rather than conflict. As practiced by FAA/AST to date, there is evidence to support this. The commercial space launch industry has benefited from the environment of streamlined procedures and open communication across stakeholders that FAA/AST has helped to create, and at the same time has maintained an impressive safety record.

GAO assessment of FAA/AST's promotional duties

In its October 2006 study of the space tourism industry, the U.S. Government Accountability Office (GAO) concluded that "FAA's current promotional activities have not conflicted with its safety regulatory role."[28] However, the GAO recognized that some experts see potential for conflict in the future as the industry develops. The study also pointed out that FAA/AST and the Commerce Department's Office of Space Commercialization (OSC) have overlapping responsibilities:

> Under the Technology Administration Act of 1998, Commerce is to serve as an advocate for the commercial space industry. Its Office of Space Commercialization, established in 1988 within the Office of the Secretary of Commerce and now located within the National Oceanic and Atmospheric Administration, is responsible for promoting commercial investment in the industry by, among many activities, collecting and disseminating information on space markets; conducting workshops on commercial space opportunities; promoting space-related exports; and seeking the removal of legal, policy, and institutional impediments to space activities.[29]

GAO recommended that FAA develop a memorandum of understanding (MOU) with OSC to distinguish between the promotional responsibilities of the two offices.[30] Since the GAO published its report, an MOU has been signed, although it is not specific as to the division of duties. Rather, its objective is to "establish an expanded working relationship" by suggesting joint promotional activities such as cooperation on an unspecified annual event.[31] This agreement enables the two offices to work together, but it is unlikely that a clear delineation of duties will be established through this process.

Among OSC's performance objectives, according to its Strategic Plan, are: "Increase U.S. Government use of commercial space goods and services" and "Promote growth in the export of space-related goods and services." Strategy elements relevant to industry promotion include the following:

- OSC will work within the executive branch of the federal government to facilitate the use of commercially available space goods and services.
- OSC will coordinate with U.S. commercial space industry and other government entities to contribute to the future development of the legal, regulatory, and institutional framework for promoting space commerce, and will identify and review related issues that may impede U.S. commercial space efforts.
- OSC will increase exposure of space commerce through outreach activities such as workshops, seminars, and publications.
- OSC will encourage and facilitate private sector efforts to educate the public on the benefits and potential of space commerce.
- OSC will disseminate trend information to policy-makers, industry, and the public.[32]

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[28] U.S. Government Accountability Office (GAO), "Commercial Space Launches: FAA Needs Continued Planning and Monitoring to Oversee the Safety of the Emerging Space Tourism Industry," GAO-07-16, October 2006, p. 30.

[29] GAO, p. 13.

[30] GAO, p. 6.

[31] Memorandum of Understanding (MOU) Between the Office of Commercial Space Transportation, Federal Aviation Administration, U.S. Department of Transportation, and the Office of Space Commercialization, National Environmental Satellite, Data, and Information Service, National Oceanic and Atmospheric Administration, U.S. Department Of Commerce, September 2007.

[32] U.S. Department of Commerce, Office of Space Commercialization (OSC) Strategic Plan, "U.S. Leadership in Space Commerce," March 2007.

The GAO believes that the Commerce Department's OSC, with its mandate to promote space commerce, could take over FAA/AST's duties in this area. The GAO study states that "Commerce now has the staff resources to promote the commercial space industry, possibly eliminating the need for FAA to play a promotional role."[33] Although OSC has been reinvigorated over the past two years, GAO's view overstates the current situation. OSC (five people) has less than one-tenth the staff of FAA/AST and needs additional resources to do the tasks it is already pursuing. The responsibilities most likely to be reassigned to OSC would be the annual conference and the publications. Despite its much larger staff, FAA/AST relies significantly on contractor assistance for these activities. Clearly, any shift of these responsibilities from FAA/AST to OSC would have to be accompanied by a transfer of resources. This is likely to be disruptive, and unlikely to result in any cost savings.

Comparisons to other industries

Commercial aviation offers the most obvious analogy to the commercial human spaceflight industry. The FAA and its predecessors had a dual mandate for regulation and promotion of the airline industry that began with the Air Commerce Act of 1926[34] and continued until 1996 when Congress removed promotional responsibilities at the request of the Secretary of Transportation.[35] This change occurred in the wake of the ValuJet Flight 592 crash of May 11, 1996. The rationale for this action was given in the legislation's conference report:

> The Managers have adopted provisions from both the House and Senate bills to clarify that the FAA's highest priority is safety and security… the provision is intended to address any public perceptions that might exist that the promotion of air commerce by the FAA could create a conflict with its safety regulatory mandate.[36]

This indicates that promotion of the commercial airline industry was eliminated from FAA's responsibilities due to concerns over public perceptions rather than any documented conflict of interest, and only after the FAA had been performing this function for several decades. Notably, not everyone in Congress agrees with the 1996 change. In June 2005, Congressman Todd Tiahrt of Kansas introduced legislation to restore the FAA's promotion role. The Promotion Responsibility for Our U.S. Aviation Act was reintroduced in the 110th Congress in February 2007, but so far has not made it out of committee.[37]

As with any regulatory function of the U.S. government, there is always a danger that a relationship could develop between the regulator and industry that becomes too cozy and results in lax enforcement. This is what many observers of the FAA, including members of Congress, believe to have been the cause of the airline maintenance lapses that resulted in the cancellation of scores of flights in early 2008.[38] Having given up its role in promoting air travel more than a decade earlier, it is clear that any inappropriate relationship with industry or enforcement shortcomings at FAA that may have contributed to this situation were caused by something other than a conflict between promotion and regulation. FAA/AST and its management chain at the Department of Transportation must remain vigilant

33 GAO, p. 40.
34 Federal Aviation Administration (FAA), "A Brief History of the Federal Aviation Administration," http://www.faa.gov/about/history/brief_history/, accessed January 2008.
35 Federal Aviation Authorization Act of 1996, Public Law 104-264, Sec.401, "Elimination of Dual Mandate."
36 Federal Aviation Authorization Act of 1996, Conference Report 104-848, explanatory statement 29, "Dual Mandate," p. 92.
37 GovTrack.us, "H.R. 1106 – 110th Congress (2007): Promotion Responsibility for Our U.S. Aviation Act of 2007," http://www.govtrack.us/congress/bill.xpd?bill=h110-1106, accessed January 2008.
38 Del Quentin Wilber, "Airlines, FAA Under Fire on the Hill; Lawmaker Links Safety Lapses to 'Cozy Relationship,' Will Hold Hearing," *Washington Post*, April 2, 2008, p. D01.

to prevent similar problems from developing in commercial space launch regulation, whether or not such circumstances are related to a promotional role.

Moving to an example in another part of the space community, the civil and commercial applications of the Global Positioning System (GPS) navigation satellites are regulated by the Department of Transportation, while promotion is the responsibility of the Department of Commerce. Commerce is directed to "promote the use of U.S. civil space-based positioning, navigation, and timing services and capabilities for applications at the Federal, State, and local level, to the maximum practical extent." However, Transportation does have promotional duties regarding "the use of U.S. civil space-based positioning, navigation, and timing services and capabilities for transportation safety" and "international acceptance for using the military positioning, navigation, and timing services of the GPS for operations in civil airspace." Additionally, the Department of State is directed to "promote the use of civil aspects of the Global Positioning System and its augmentation services and standards with foreign governments and other international organizations."[39] In this case, we find promotional responsibilities split among three agencies, including the regulatory agency. The U.S. government sees value in promoting GPS for a variety of applications but has chosen a fragmented approach to doing so, with no apparent fear of conflicts between regulation and promotion.

For the commercial satellite remote sensing industry, the National Oceanic and Atmospheric Administration (NOAA) has had the dual mandate of regulation and promotion. NOAA has chosen to handle this by putting firewalls between licensing, compliance, and advocacy functions. Discussions with Commerce Department staff revealed that this approach to segregating the duties has had a negative effect, creating stovepipes that prevent all perspectives from being considered across these activities. This separation has hindered communication and understanding, doing injustice to the industry, in the opinion of the Commerce staffers.

The dual mandate in the near-to-medium term

Regulation and promotion of many of the nation's economic activities coexist in the executive branch. At what level should they come together? The answer may be different for each industry depending on factors such as the size of the industry's contribution to the U.S. economy, the nature of international competition, the technical complexity of the industry, and the national security significance of the technologies.

The technical and historical knowledge underlying the policy and regulatory framework for the commercial space launch industry is present in just a few places within the government. FAA/AST is foremost among these, with a legacy that goes back to 1984. Industry representatives contacted for this study unanimously felt that FAA has been performing its promotional duties well, without compromising its safety responsibilities, and should retain this mandate. At this stage in the evolution of the industry, and for the next few years, there is no compelling reason to uproot the promotional duties and shift them elsewhere. As noted by the GAO, the only other federal government office that would be a logical home for these duties is the Commerce Department's OSC. Despite GAO's belief that OSC is ready to assume these responsibilities, such a transition at this time would be a disruptive attempt at a solution to a non-existent problem. The current staff at OSC has expressed no eagerness to take on these tasks given what they have on their plate already, but OSC has demonstrated a willingness to work more closely with FAA/AST when appropriate.

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[39] George W. Bush, National Security Presidential Directive (NSPD) 39 Fact Sheet, "U.S. Space-Based Position, Navigation, & Timing Policy," December 15, 2004.

The U.S. government's mandate to promote the commercial airline industry lasted for seven decades, and was ended due to concerns about public perceptions rather than real problems. For the commercial launch industry, one needs to ask: What criteria should the government use to determine when it should terminate promotional efforts? In the absence of a clear case of conflict of interest (e.g., compromise of public safety, industry complaints of favoritism toward particular companies or vehicles), other specific criteria for termination seem arbitrary (e.g., global market share, number of successful U.S. competitors, industry growth rates in revenues or profits, number of spaceflight participants per year). No such criteria were used to judge the promotional role for the airline industry. As in the airline case, there may come a time when the Department of Transportation, the industry, or both decide that federal government promotional efforts are no longer appropriate or needed. That is not the case today, and is not likely to be in the next few years. Meanwhile, the FAA/AST resources devoted to promotion are a small part of its budget, and in general reinforce rather than conflict with safety responsibilities.

Experts have noted the potential for conflicts of interest to arise at some point in the industry's development, but there are no examples of this having occurred to date, and none that are likely in the next few years as long as FAA/AST continues to follow its current procedures for licensing and compliance monitoring. The commercial space launch industry will experience significant changes in its environment in the coming decades, so periodic review of this issue is warranted. However, in the period of primary concern for this study (through 2012), there is no apparent urgency and no clear benefit to be derived from changing FAA/AST's dual mandate.

Topics 6 and 7
How could third parties be used to evaluate the qualification and acceptance of new human space flight vehicles prior to their operation?
How could non-government experts participate more fully in setting standards and developing regulations concerning human space flight safety?

Topic 6 Conclusion: The CSLA defines third parties, for purposes of commercial space launch activities, as the uninvolved public. Independent experts such as consultants and non-government personnel are typically part of the process and are essential to the qualification and acceptance of new human spaceflight vehicles. However, we make no specific recommendations on how they should be used because, in the current early stage of development, each situation will require different expertise and will be best handled on a case-by-case basis.

Topic 7 Conclusion: In setting standards and regulations, the government frequently uses outside expertise to augment its own personnel. Often outside personnel are experts from the specific industry being regulated, consultants, and academia. There are many ways private sector experts are involved in the standards and regulatory process, ranging from providing expertise in a particular technical field to serving as members of review, advisory, and accident investigation panels. Each specific circumstance is unique, and there is no reason at this time to recommend any changes to this system. However, in a related area, the National Transportation Safety Board (NTSB), an independent government agency, does not have space transportation explicitly included in its statutory jurisdiction, although it does have agreements with the FAA and the Air Force under which the NTSB will lead investigations of commercial space launch accidents. Congress may want to consider explicitly designating a lead agency for accident investigations involving space vehicles to avoid potential overlapping jurisdictions.

Topics 6 and 7 have been combined because of the similarity of the questions. The response to Topic 6 requires looking more broadly at "third parties" than suggested by the narrow definition of that term in the CSLA. The statute essentially defines third parties as the uninvolved public, but the discussion here also addresses questions concerning consultants and other expert assistance from non-governmental entities.[40]

The CSLA defines third parties as follows:

Third party means a person except –
(A) the United States Government or the Government's contractors or subcontractors involved in launch services or reentry services;
(B) a licensee or transferee under this chapter;
(C) a licensee's or transferee's contractors, subcontractors, or customers involved in launch services or reentry services;
(D) the customer's contractors or subcontractors involved in launch services or reentry services; or
(E) crew or space flight participants.[41]

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[40] Although under certain conditions foreign government agencies and NGOs could be considered third parties under the CSLA definitions, they will be discussed in this analysis in the same general context as consultants, advisory bodies to the U.S. government, and other expert advice.

[41] Title 49 USC – Transportation, Subtitle IX – Commercial Space Transportation, Chapter 701 – Commercial Space Launch Activities, Sec. 70102(21).

This definition was placed in the legislation to fulfill the nation's responsibility under the U.N. Outer Space Treaty and the Liability Convention and usually refers to a case where an incident occurs that results in damage to another's property in space, on the surface of the Earth, or on aircraft in flight.[42,43] It also forms the basis for determining who should pay for those damages. FAA rules on financial responsibility adequately deal with these situations, at least in the near term. Clearly this application of the definition is not central to the questions addressed in this report.

According to the above definition, anyone directly involved in the development of a new space vehicle, whether for human spaceflight or for cargo, who works for the government or for industry, or is a spaceflight participant, is not a third party. If we look beyond the formal definition and include sources of expertise outside of the immediate stakeholders, there are some important issues that can be raised that will address concerns the Congress may have.

Certification of aircraft under the FARs and the "certification" of space vehicles[44]

There is significant difference between the certification of aircraft under the FARs and the "certification" of space vehicles, in particular the space shuttle. The certification of commercial human-rated spacecraft has not been defined or implemented. The interaction between the FAA and the spaceflight industry will be different than that between the FAA and the aviation industry for the certification of airplanes, particularly in regard to the comprehensiveness of information provided by the manufacturers and operators. At least for now, under the CSLA Amendments of 2004, the FAA is prohibited from regulating the design of space vehicles in ways that are not relevant to the safety of the uninvolved public. That opens a question as to whether standard practices in aviation can or should be applied to experimental spacecraft, at least until 2012.

Recent studies have found the following:

> FAA's safety review of a license includes the review of data provided by the license applicant on the proposed flight path of the launch vehicle and a determination of its potential risk to the noninvolved public and property. Federal launch sites conduct their own risk analysis, which FAA reviews.[45]
>
> …safety standards may differ for RLVs carrying crew only versus RLVs carrying fare-paying passengers. Furthermore, the similarities and differences between aviation requirements and RLV safety standards deserve considerable attention. Certainly RLVs cannot be expected to demonstrate aircraft-like reliability on the first day of operations,

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42 Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (1967), art II, 18 UST 2410, 2413 (1969).

43 Convention on International Liability for Damage Caused by Space Objects (1972), art IV, 24 UST 2389, 2393 (1973). Although both of these Treaties are limited to damage to third parties in other nations, the licensing regulations of the FAA for commercial space activities requires companies to show financial responsibility (i.e., have insurance and/or the ability to cover damages at a preset maximum probability of loss regardless of where the damage occurs. Above that amount, the U.S. government will indemnify third-party damages up to $1.5 billion, adjusted to current inflation levels for U.S. licensed space activities.

44 Recent newspaper articles following the problems in certification procedures with some airlines (e.g., Southwest) have resulted in an investigation by the DOT IG office. Because this investigation is ongoing, this report will not address this issue.

45 GAO, p. 52, footnote 1.

Summary of Aviation Regulations

The U.S. government has controlled design, production, and certification of general aviation and commercial aircraft since 1922. The Federal Aviation Act of 1958 established the FAA and authorized responsibility for ensuring aviation safety and promoting civil aviation. The Federal Aviation Regulations (FARs) are found in Title 14, Chapter 1 of the Code of Federal Regulations (CFRs) and provide the regulatory framework for general aviation and commercial aircraft. The FARs are based on fail-safe design concepts that have evolved over a period of years. The "Airworthiness Standards" for various category aircraft are addressed in 14 CFR parts 23, 25, 27, 29, and 31, and are categorized as follows:
Part 23: Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes
Part 25: Airworthiness Standards: Transport Category Airplanes
Part 27: Airworthiness Standards: Normal Category Rotorcraft
Part 29: Airworthiness Standards: Transport Category Rotorcraft
Part 31: Airworthiness Standards for Manned Free Balloons

Each of these Parts includes Subparts categorized as follows:
Subpart A: General
Subpart B: Flight
Subpart C: Structure (designated "Strength Requirements" for parts 27 and 29).
Subpart D: Design and Construction
Subpart E: Powerplant
Subpart F: Equipment
Subpart G: Operating Limitations and Information
In addition to the FARs, concomitant Advisory Circulars also play an important role in the process of ensuring public and passenger safety, as they provide various acceptable means of showing compliance with the requirements of the FARs. The principal Advisory Circulars addressing safety of airplane systems are AC 23.1309 1-3, Equipment, Systems, and Installations in Part 23 Airplanes, and AC 25.1309-1A, System Design and Analysis.
Source: Patel, et al., pp. 47-48.

so some learning curve or phased licensing must be allowed. Options for such a phased licensing approach need to be explored.[46]

Aircraft are not subjected to the same environmental extremes as launch vehicles. However aircraft do share with launch vehicles the pre-take-off, subsonic ascent, and landing/post-landing flight phases.[47]

Government agencies involved in human spaceflight

The October 2006 GAO report on commercial space launches displayed a list of agencies involved in commercial space flight, reproduced in Figure 3 below. All agencies listed, to some extent, are involved in safety issues. This list is not complete, since agencies such as Cal-OSHA (involved in July 2007 investigation of the ground accident at Scaled Composites), the NTSB (see below), Congress, and the Judiciary, will have roles to fulfill as commercial space matures. Each agency, subject to unknown

46 N.R. Patel, J.C. Martin, R. J. Francis, and R. W. Seibold, *Human Flight Safety Guidelines for Reusable Launch Vehicles*, Final Report, U.S. Department of Transportation Contract DTRS57-99-D-00062, Tasks 2 and 3, Aerospace Corporation Report ATR-2003(5050)-1, July 31, 2003, p.1.

47 Patel et al., p. 157.

future conditions and incidents concerning human spaceflight, will need non-governmental expertise. However, predicting today what type and where expertise will be needed is not possible, given the absence of commercial human spaceflight experience.

Agency	Description of Roles and Responsibilities
Commerce	• Promotes commercial investment in the industry and sales of U.S. goods and services internationally • Develops policies to improve the international competitiveness of the U.S. industry and advocates for the U.S. industry in international competitions • Is a customer for satellite and launch services
DHS	• Responsible for security at spaceports
DOD	• Provides infrastructure, operations support, and safety oversight at federal launch sites • Provides investment in launch vehicle design and development • Is a customer for satellite services and launches
FAA	• Issues and monitors licenses for launches and reentries and for launch and reentry sites for the safety of the public and protection of property • Determines financial responsibility, including insurance requirements • Promotes the industry
NASA	• Provides infrastructure and range support at its launch site at the Wallops Flight Facility • Provides tracking and telemetry support for commercial launches from NASA and DOD launch sites • Provides technical expertise to commercial launch companies on a cost-reimbursable or mutually beneficial basis • Leases rocket propulsion test facilities to commercial space launch companies • Provides business opportunities through prize competitions • Is a customer for launches
OSTP NSC	• Develops and manages commercial space launch policymaking among federal agencies
State	• Ensures that U.S. space policies are in accordance with U.S. foreign policy objectives and international commitments • Regulates export of space technology
USTR	• Negotiates and monitors commercial space launch industry trade agreements

Figure 3. Agency Roles and Responsibilities

Source: Government Accountability Office, "Commercial Space Launches: FAA Needs Planning and Monitoring to Oversee the Safety of the Emerging Space Tourism Industry," GAO-07-16, October 2006, p. 15.

National Transportation Safety Board (NTSB)

The NTSB has jurisdiction over safety aspects in all forms of transportation. As described on its website, the NTSB is an independent federal agency charged by Congress with investigating every civil aviation accident in the United States and significant accidents in the other modes of transportation – railroad, highway, marine and pipeline – and issuing safety recommendations aimed at preventing future accidents. NTSB determines the probable cause of:

- all U.S. civil aviation accidents and certain public-use aircraft accidents;
- selected highway accidents;
- railroad accidents involving passenger trains or any train accident that results in at least one fatality or major property damage;
- major marine accidents and any marine accident involving a public and a nonpublic vessel;

- pipeline accidents involving a fatality or substantial property damage;
- releases of hazardous materials in all forms of transportation; and
- selected transportation accidents that involve problems of a recurring nature.

The NTSB has issued more than 12,000 recommendations in all transportation modes to more than 2,200 recipients. More than 82 percent of its recommendations have been adopted by those in a position to effect change. Many safety features currently incorporated into airplanes, automobiles, trains, pipelines and marine vessels had their genesis in NTSB recommendations.[48]

Space transportation is not explicitly included in the statutory jurisdiction of the NTSB.[49] However, the NTSB is charged with determining probable cause of transportation accidents and promoting transportation safety. In the future, as private spaceflight matures, Congress could give the NTSB explicit authority over spaceflight accident investigations.

Notwithstanding the above, there has been in effect a Memorandum of Understanding (MOU) with the DOT/FAA Associate Administrator for Commercial Space and the NTSB that gives the NTSB the authority to investigate commercial space launch accidents. The first agreement was executed in 2000 as an Appendix to a 1975 DOT MOU with the NTSB that transfers to the NTSB the lead in accidents that result in loss of life and/or in property damage over $25,000.[50] In addition there is an agreement signed in 2004 between the FAA, the U.S. Air Force, and the NTSB that allocates responsibilities for launch accidents among those parties.[51]

Therefore, although space accidents are not part of the legislative mandate of the NTSB, the lead for investigating launch vehicle accidents under the jurisdiction and license of the FAA may be delegated to the NTSB. There is currently a statutory overlap and potential conflict for certain types of launch vehicle accidents between the NTSB and language in the NASA Authorization Act of 2005 that directs the President to appoint a special accident investigation board to investigate launch vehicle accidents of commercial vehicles under government contract.[52] Congress should take note of this potential legislative overlap in jurisdiction and clarify the roles of the various agencies in the event of a space launch vehicle accident.

Use of non-government personnel

The use of outside expertise in aerospace safety is both necessary and helpful. Neither the FAA nor other involved agencies have sufficient personnel or expertise to handle both the day-to-day operations and the special questions and needs that may arise in this industry to deal with new technologies and accident investigations.

Non-governmental personnel are an integral and important part of the aerospace safety regime. They are employed as advisory committee members, contractors to both the government and industry, and as consultants. Beyond these formal relationships, there are myriad ways that non-government personnel

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48 http://www.ntsb.gov/Abt_NTSB/history.htm (accessed 3/23/2008)

49 The NTSB has assisted in accident investigations involving commercial communications satellites and participated (though not in the lead role) in the investigations of the *Challenger* and *Columbia* space shuttle accidents. Telephone conversation with Gary Halbert, NTSB General Counsel, July 29, 2008.

50 Appendix H to the Reimbursable Memorandum of Agreement between the DOT and the NTSB of 1975, signed on 1/3/2000.

51 Memorandum of Agreement between the NTSB, the Department of the Air Force, and the FAA Regarding Space Launch Accidents, signed in August of 2004.

52 See discussion below under *Special Review Panels*.

are involved, ranging from congressional testimony on relevant issues to working with and for quasi-governmental organizations such as the National Academies and Federally Funded Research and Development Centers. Some of the above relationships are long-term and some only for limited periods of time. Since the use of non-governmental personnel is a continuing process, this topic focuses on a brief review of major space-related advisory panels and committees that use outside expertise.[53]

Commercial Space Transportation Advisory Committee (COMSTAC)

Established in 1984, COMSTAC provides information, advice, and recommendations to the Administrator of the FAA within the Department of Transportation (DOT) on matters relating to the U.S. commercial space transportation industry. COMSTAC addresses industry issues through its working groups, which provide information, reports and recommendations to the full Committee for adoption. If a report or recommendation is adopted by the full Committee, it is then submitted to the FAA Administrator as an official industry recommendation. COMSTAC currently has four working groups: Technology and Innovation, Space Transportation Operations Support, Risk Management, and Reusable Launch Vehicle. Ad hoc working groups or special task groups are also established to address specific short-term issues or current critical issues. Working groups meet as needed.

The primary goals of COMSTAC are to:

- Evaluate economic, technological and institutional developments relating to the U.S. commercial space transportation industry.
- Provide a forum for the discussion of problems involving the relationship between industry activities and government requirements.
- Make recommendations to the Administrator on issues and approaches for federal policies and programs regarding the industry.

COMSTAC membership is made up of senior executives from the commercial space transportation industry; representatives from the satellite industry, both manufacturers and users; state and local government officials; representatives from firms providing insurance, financial investment, and legal services for commercial space activities; and representatives from space advocacy organizations, academia, and industry associations.[54]

NASA Aerospace Safety Advisory Panel

Since it was established in 1968, after the Apollo 1 fire that killed three astronauts, the Aerospace Safety Advisory Panel (ASAP) has been evaluating NASA's safety performance and advising the agency on ways to improve that performance. The ASAP bases its advice on direct observation of NASA operations and decision-making. In the aftermath of the Shuttle *Columbia* accident, Congress required that the ASAP submit an annual report to the NASA Administrator and to Congress. The annual report is to examine NASA's compliance with the recommendations of the Columbia Accident Investigation Board, as well as NASA's management and culture related to safety. In addition to safety culture, NASA Administrator Michael Griffin, has specifically requested advice from the ASAP on technical authority, workforce, and risk management.[55]

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53 All U.S. government advisory committee activities are governed by the Federal Advisory Committee Act (Pub. L. 92-463, Sec. 1, Oct. 6, 1972, 86 Stat. 770) which requires advisory committees to be fairly balanced in terms of points of view (§5(b)(2) and contain appropriate provisions to assure that the advice and recommendations of the advisory committee will be … the result of the advisory committee's independent judgment (§5(b)(3).

54 http://www.faa.gov/about/office_org/headquarters_offices/ast/advisory_committee/ (accessed 3/23/2008)

55 http://www.hq.nasa.gov/office/oer/asap/index.html (accessed 3/23/2008)

Special Review Panels

Independent commissions have routinely been established after a major space accident to investigate the causes and make recommendations to the federal government for reducing the probability of future accidents. To formalize this process, as part of the NASA Authorization Act in December 2005, Congress made it a requirement of the President to establish an independent, nonpartisan commission if there is an incident that results in the loss of: (1) a space shuttle, (2) the ISS or its operational viability, (3) any other U.S. space vehicle carrying humans that is owned by the federal government or that is being used pursuant to a contract with the federal government, or (4) a crew member or passenger or any space vehicle described in the statute.[56]

Although the legislation might not apply to all future commercial human space flights, it will likely apply to some of them since at least one of the companies developing commercial space endeavors has also received contracts from the federal government for flight opportunities. A largely open question remains concerning how flights of private commercial vehicles involved in an accident would be treated if the same class of vehicles were also concurrently flying government payloads under contract. In addition, the companies that have received COTS funds from NASA would be included since the ISS is specifically listed in the legislation.

Other non-government sources of advice

Public responses to proposed U.S. rules and regulations

As per the Administrative Procedures Act, all proposed rules must be published in advance, public hearing held, and the public must be given an opportunity to submit written comments. Agency response to those comments is required in the issuance of the formal ruling, and any interested person has the right to petition for the issuance, amendment, or repeal of the rule.[57]

Professional associations, institutes, and NGOs

There are many national and international aerospace organizations that actively convene conferences, hold public and technical meetings, and issue position papers on space safety issues. The membership of these organizations includes both government and non-government personnel and the organizations provide a very important forum for the dissemination of information, the debate on issues, and for technical expertise.

Below is a list of selected U.S. and international organizations that perform these functions, each in a different way, but all involving non-governmental personnel in their activities and all in some way having a potential effect on the safety of humans in space flight.

Aerospace Industries Association (AIA)
American Astronautical Society (AAS)
American Institute of Aeronautics and Astronautics (AIAA)
International Academy of Astronautics (IAA)
International Association for the Advancement of Space Safety (IAASS)
International Astronautical Federation (IAF)
International Civil Aviation Organization (ICAO)

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56 42 U.S.C. 16841, Public Law 109-155, Title V §821, Dec. 30, 2005, 119 Stat. 2941.
57 United States Code, Title 5, Part I, Chapter 5, Subchapter II, §533(b) and (c)

International Telecommunications Union (ITU)
Institute of Electrical and Electronics Engineers (IEEE)
Personal Spaceflight Federation (PSF)
Society of Automotive Engineers (SAE)
Space Transportation Association (STA)
United Nations Committee on the Peaceful Uses of Outer Space (UNCOPUOS)
World Intellectual Property Organization (WIPO)

As noted in other sections of this report, there are non-U.S. regulatory proposals that will deal with safety issues and regulations for commercial human spaceflight. In particular Europe and Russia are considering entering this business and, if they do, they will promulgate their own set of laws and regulations for those vehicles and services. They might take a more proactive approach to government regulation and issue strong safety regulations in advance of the development of the industry. This position is very different from the current position of United States legislation that takes a minimalist approach to help stimulate the growth of the industry and to encourage self-regulation of those developing human-rated commercial space vehicles.

Technical and Standards Development (ISO organization)

The International Organization for Standardization (ISO) is an example of an international organization that develops non-binding standards affecting safety, although it is not directly involved in safety oversight. It is the world's largest developer and publisher of international standards, with a network of national standards institutes in 157 countries and a central secretariat in Geneva, Switzerland, that coordinates the system.

ISO is a non-governmental organization that forms a bridge between the public and private sectors. In many cases, its member institutes are part of the governmental structure of their countries, or are mandated by their government. In contrast, some members have their roots uniquely in the private sector, having been set up by national partnerships of industry associations. Therefore, ISO enables a consensus to be reached on solutions that meet both the requirements of business and the broader needs of society.[58]

The space insurance industry[59]

The insurance industry has a clear financial stake in assuring the safety of humans in spaceflight. However, the industry has not been proactive with government agencies on specific safety issues and generally is reactive to accidents in its risk assessment and rate-setting functions. The basic questions evaluated by the industry are: (1) the insurability of the event, and (2) the available pool of insurance funds at the time of the event.

Insurance underwriters visit space hardware manufacturing plants and receive briefings from the companies before writing space insurance policies. Space insurers do not become involved in highly technical space issues because of export control restrictions in the United States and because they often have insufficient in-house technical personnel or expertise. The insurance business is global. Many of the insurers or re-insurers are headquartered outside of the United States. Therefore, the export control issues imposed by the U.S. government are a significant deterrent to deep involvement in technical safety issues.

[58] http://www.iso.org/iso/about.htm (accessed 3/23/2008)
[59] The comments in this section are based on recent discussions with experts in the insurance industry who requested anonymity.

Insurance industry experts are members of the COMSTAC and often testify on safety issues before congressional committees. But their role is not technical. As the commercial human spaceflight industry matures and a better actuarial data base is developed on all space launches, their involvement in the process and implementation for safety regulations could expand.

Summary

The regulatory regime in the United States involves a large number of people, both within and outside the government. Many parts of the regulations also are coordinated with international organizations and treaty regimes. As a consequence, there are many different sources of ideas, information, and legislative and regulatory initiatives, each requiring detailed study and analysis. Furthermore, the need to continuously evaluate the effectiveness of the existing regulations and implement new ones is an ongoing government responsibility in response to accidents, new policy initiatives, and rapidly changing technologies.

Therefore, it is not only useful for government agencies to make provisions for the extensive use of outside expertise, it is essential. It is virtually impossible for any one agency such as the FAA to employ as civil servants either the number of people necessary to carry out all of the functions or to have all of the in-house expertise that is needed in this highly technical and complex industry.

There are a variety of ways that non-governmental personnel, consultants, and other experts not directly employed by the U.S. government are used in the technical and advisory functions that oversee new aerospace vehicles. There are many agencies involved in private space activities and each has its own agenda and approach to using outside expertise. The methods of employment, fields of expertise, and functions these people and organizations are involved in span the entire spectrum of the design, development, deployment, and regulatory aspects of the vehicles. Examples include:

- certification and/or approval of technologies and completed vehicles;
- supplementing government employees where specific expertise is not present and/or more people are needed to perform a function than are available from government sources;
- advisory panels of outside experts that function in an oversight role;
- special panels convened for a specific purpose (e.g., accident investigations);
- professional associations that make recommendations based on their specific specialties;
- the general public's responses to proposed new regulation during the period reserved for formal responses, as well as public participation in government-convened town meetings, symposia, workshops, panels, and other public events.

Because of the wide variation in disciplines, agencies, and uses of non-government personnel, and because the private human spaceflight industry is still in its early states of development and is characterized by many different technical and practical approaches to spaceflight, making specific recommendations on how to use outside personnel is not appropriate at this time. We find no need to change the many formal and informal mechanisms that the government currently uses to obtain expert help. The FAA should continue to use these mechanisms as they have in the past to help develop adequate and reliable safety standards for human spaceflight.

The one recommendation that we do make is for Congress to review potential future overlapping jurisdiction that might occur in the event of a space accident involving private space participants. The selection of which agency or special commission is the lead entity in the investigation is not at issue since there is ample evidence of excellent interagency cooperation and coordination on this matter. What will be important is making sure that clear legislation exists to insure that bureaucratic delays are avoided and that the regulatory authorities can act quickly and efficiently to avoid future problems.

Topic 8
Should the federal government regulate the extent of foreign ownership or control of human spaceflight companies operating or incorporated in the U.S.?

Conclusion: Commercial human spaceflight is an emerging industry that does not yet have a significant impact on the U.S. economy, play a role in national security, or control militarily significant technologies that are unique to the United States. Therefore, it does not have characteristics that traditionally have provided the rationale for regulating foreign ownership. Imposition of foreign investment limits could undermine the industry's ability to succeed and grow.

The U.S. government has imposed foreign ownership limits on various U.S. companies and industries, primarily due to their vital national security capabilities. This section will review U.S. government criteria for restricting foreign investment to determine its applicability to commercial human spaceflight. This will assist the Congress in judging whether the industry's ownership structure may require special attention regarding economic, technological, or security issues.

Foreign ownership limits: policy and law

> International investment in the United States promotes economic growth, productivity, competitiveness, and job creation. It is the policy of the United States to support unequivocally such investment, consistent with the protection of the national security.[60]

As indicated in the 2008 Executive Order quoted above, the U.S. government views foreign investment as good for the nation, but it also monitors and sometimes restricts this behavior to safeguard national security interests. For example, foreign investors are constrained by statutes that limit foreign direct investment in such industries as aircraft, shipping, communications, mineral resources, and power to prevent public services and public interest activities from falling under foreign control.[61] [see box]

Legal restrictions on foreign investment

Aircraft operations: A corporation or association operating aircraft in the United States must have U.S. citizens holding the positions of president and two-thirds or more of the board of directors and other managing officers. At least 75 percent of the voting interest must be owned or controlled by persons who are U.S. citizens. (49 U.S.C. §40102(a)(15))

Shipping: Three major maritime laws have provisions concerning barriers to foreign investment: the Shipping Act of 1916, the Merchant Marine Act of 1929, and the Merchant Marine Act of 1936, all contained within Title 46 of the U.S. Code.

Communications: Radio station licenses shall not be granted to or held by any foreign government or representative of a foreign government. (47 U.S.C. §310(a))

Mining: All valuable mineral deposits in lands belonging to the United States that are open to exploration and purchase may be purchased by U.S. citizens and by those who have declared their intention to become United States citizens. (30 U.S.C. §22)

Energy: Licenses for the construction, operation, or maintenance of facilities for the development, transmission, and utilization of power on land and water over which the federal government has control may be issued only to U.S. citizens and domestic corporations (16 U.S.C. §797(e)). A license for nuclear facilities cannot be acquired by a foreign citizen or by a corporation believed to be controlled by a foreign citizen or government (42 U.S.C. §2133(d)).

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60 George W. Bush, Executive Order 13456: "Further Amendment of Executive Order 11858 Concerning Foreign Investment in the United States," January 23, 2008.

61 Congressional Research Service (CRS), "Foreign Investment in the United States: Major Federal Statutory Restrictions," September 21, 2005, pp. 9-15.

Despite these restrictions, by the late 1980s Congress and the public grew concerned about increases in foreign investments and their potential impacts on the U.S. economy. Section 5021 of the Omnibus Trade and Competitiveness Act of 1988, often called the Exon-Florio provision, amended the Defense Production Act of 1950 to allow the President or the President's designee (the Secretary of the Treasury) to investigate the effects on national security of mergers, acquisitions, and takeovers by foreign persons which could result in foreign control of interstate commerce in the United States. Joint ventures and licensing agreements originally had been included in the proposed legislation, but were dropped because the Reagan administration and industry groups argued that these business practices are generally beneficial to U.S. companies. They also maintained that potential threats to national security could be addressed by the Export Administration Act and the Arms Control Export Act.[62]

Section 837(a) of the National Defense Authorization Act for Fiscal Year 1993 (the Byrd Amendment) amended Exon-Florio to *require* an investigation when an "entity *controlled by or acting on behalf of a foreign government* seeks to engage in a merger, acquisition, or takeover which could result in control of a person engaged in interstate commerce in the United States that could affect the national security of the United States."[63] [emphasis added]

Congress did not intend for the Exon-Florio provision to stifle the generally open foreign investment climate in the U.S. or inhibit foreign direct investments in industries that did not affect national security interests. In determining the effects on national security, the administration may consider the following factors:

1. domestic production needed for projected national defense requirements;
2. the capability and capacity of domestic industries to meet national defense requirements, including the availability of human resources, products, technology, materials, and other supplies and services;
3. the control of domestic industries and commercial activity by foreign citizens as it affects the capability and capacity of the United States to meet the requirements of national security;
4. the potential effects of the transaction on the sales of military goods, equipment, or technology to a country that supports terrorism, missile technology proliferation, or chemical and biological weapons proliferation; and
5. the potential effects of the transaction on United States technological leadership areas affecting United States national security.[64]

Given these factors, the relevant question is: Which of them, if any, are applicable to the commercial human spaceflight industry? Since this is a new industry that provides no goods or services in support of national security, none of the factors directly apply at this time. Any connection to national security capabilities would be indirect. For example, a human spaceflight company could have suppliers that are defense contractors, but this should not raise concerns about the level of the company's foreign investment.

At some point in the future, there may be companies that are vital contributors to national security which also engage in commercial human spaceflight ventures. For example, Lockheed Martin could market its Atlas 5 to space tourists as well as to its traditional government customers. In the entrepreneurial community, SpaceX's Falcon 9 could successfully win business from the Defense Department and become a key element of assured access to space, and at the same time offer its human-

62 Congressional Research Service (CRS), "The Committee on Foreign Investment in the United States (CFIUS)," July 23, 2007, p. 8.
63 CRS (2005), p. 22.
64 CRS (2005), p. 22.

rated Dragon capsule for commercial human spaceflight. If circumstances such as these become reality, the companies involved would be candidates for review based on the five factors listed above, if they were not already subjected to this scrutiny. This situation seems plausible sometime in the coming decade. However, the current stage and pace of entrepreneurial development, and the existing contractual commitments and launch schedules of U.S. government agencies, make such circumstances unlikely by 2012.

Foreign ownership limits: history and practice

The Committee on Foreign Investment in the United States (CFIUS) was established in 1975 to monitor the economic effect of foreign investment in the United States. CFIUS is an inter-agency committee chaired by the Secretary of the Treasury and including the Secretaries of State, Defense, Commerce, and Homeland Security; the Attorney General; the Directors of the Office of Management and Budget and the Office of Science and Technology Policy; the Assistant to the President for National Security Affairs; the Assistant to the President for Economic Policy; the U.S. Trade Representative; and the Chairman of the Council of Economic Advisers. In 1988, Congress expanded CFIUS authorities to include review of foreign acquisitions of U.S. firms to make sure there was no harm to national security (and more recently, homeland security) and to allow the President to block a sale if a threat of harm existed.[65]

The Treasury Department has provided some guidance to firms on whether they should notify CFIUS of a proposed or pending merger, acquisition, or takeover. Proposed acquisitions that involve "products or key technologies essential to the U.S. defense industrial base" need to notify CFIUS, but not those that produce goods or services with no special relation to national security, especially toys and games, food products, hotels and restaurants, or legal services. In order to assure an unimpeded inflow of foreign investment, CFIUS aims to implement U.S. law "only insofar as necessary to protect the national security," and "in a manner fully consistent with the international obligations of the United States."[66]

The Congressional Research Service has noted that:

> According to anecdotal evidence, some firms apparently believe that the CFIUS process is not market neutral, but that it adds to market uncertainty that can negatively affect a firm's stock price and lead to economic behavior by some firms that is not optimal for the economy as a whole. Such behavior might involve firms expending a considerable amount of resources to avoid a CFIUS investigation, or deciding to terminate a transaction that would improve the optimal performance of the economy in order to avoid a CFIUS investigation. While such anecdotal evidence does not provide enough evidence to serve as the basis for developing public policy, it does raise a number of concerns about the possible impact of the CFIUS process on the market and the potential costs of redefining the concept of national security relative to foreign investment.[67]

Elsewhere in the same report, CRS pointed out that: "The potentially negative publicity that can be associated with a CFIUS investigation of a transaction apparently has had a major impact on the transactions CFIUS has investigated. Since 1990, nearly half of the transactions CFIUS investigated were terminated by the firms involved, because the firms decided to withdraw from the transaction rather than

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65 Department of the Treasury (DoT), "Committee on Foreign Investment in the United States (CFIUS)," http://www.treas.gov/offices/international-affairs/exon-florio/, accessed January 2008.

66 Senate Armed Services Committee (SASC), Briefing on the Dubai Ports World Ports Deal, February 23, 2006, as quoted in CRS 2007.

67 CRS (2007), p. 23.

face a negative determination by CFIUS."[68] This statement seems to indicate that there is data to support the anecdotal evidence. Commercial human spaceflight firms could become wary of possible negative public and investor perceptions of their competence and market value if CFIUS investigations were to be initiated on a case-by-case basis. However, the number of cases requiring investigation has been a very small percentage of the total cases filed. Here are the statistics from 1988 through January 2006:

Alternative arrangements for ownership and control

Canadian law does not permit a foreign investor to hold a controlling interest in a telecommunications company. When Loral Space & Communications and its Canadian partner, the Public Sector Pension Investment Board (PSP), decided to acquire satellite operator Telesat Canada, their relative financial investment was 64 percent Loral and 36 percent PSP. However, to conform to Canadian law, the voting equity is held one-third by Loral and two-thirds by PSP. [Peter B. De Selding, "At Deal's Close, Telesat, Loral Begin Merging Satellite Fleets," *Space News*, November 5, 2007] Similar arrangements may be used to alleviate the U.S. government's concerns about foreign control while allowing a foreign investor to choose a preferred level of financial investment.

The Civil Aeronautics Act of 1938 specifies that U.S. citizens must own or control at least 75 percent of the voting stock of U.S. airlines. [GAO, footnote 74, p. 2] However, like the Canadian example above, other financial arrangements such as non-voting preferred stock could allow foreign investors to hold a *financial* interest in a U.S. airline that exceeds 25 percent, while their *voting* interest remains within the legal limit (although currently this is not true for any U.S. airline).

- More than 1600 notices filed with CFIUS.
- Investigation required for 26 transactions (five of these after September 11, 2001).
- Of the 26 investigations, 12 were sent to the President for a decision as to whether to block the transaction.
- Of the 12 cases that were sent to the President, only one was prohibited (China National Aero Technology Import & Export Corp. was required to sell its interest in Seattle-based aircraft component company Mamco Manufacturing Inc. in 1990).[69,70]

This demonstrates the rarity of CFIUS filings resulting in investigations, and the even lower likelihood of the President intervening to halt a business acquisition by a foreign entity. The President can exercise the authority to block a foreign acquisition of a U.S. corporation only if it is found that:

(1) there is credible evidence that the foreign entity exercising control might take action that threatens national security, <u>and</u>
(2) the provisions of law, other than the International Emergency Economic Powers Act, do not provide adequate and appropriate authority to protect the national security.[71]

One of the reasons for the low number of investigations is that companies make concessions to the U.S. government before their CFIUS filing, or informally after they have begun the CFIUS process. Concessions can take many forms, such as a pledge that only U.S. citizens would be allowed to perform

68 CRS (2007), p. 12.
69 Organization for International Investment (OII), Fact Sheet: "Committee on Foreign Investment in the United States (CFIUS)," http://www.ofii.org/facts_figures/cfius.cfm, accessed January 2008.
70 James A. Lewis, "CFIUS - The Committee on Foreign Investment in the United States," Center for Strategic & International Studies (CSIS), February 2006.
71 DoT CFIUS web page.

certain jobs, or that all research would be performed within the United States.[72] Concessions like these do not necessarily cut off access to foreign capital, and in fact may be the best way to insure that foreign investments are not prohibited.

Implications for commercial human spaceflight

It is clear from the above discussion that commercial human spaceflight companies operating in the U.S. during the next several years are unlikely to raise concerns over threats to the economy or national security due to foreign direct investment. While it is hoped that someday human spaceflight will be a large and thriving commercial activity, it will be a long time before its impact on the U.S. economy evokes the level of attention that has been seen recently in the airline industry[73,74,75,76] or the foreign bailout of major U.S. financial institutions.[77]

Likewise, national security concerns related to foreign investment are not likely in the near future because the commercial human spaceflight industry does not provide products or services to the defense or intelligence communities. That could change at some point – for example, commercial human spaceflight operators could capture a significant share of U.S. government launch business, or a space launch equivalent to the Civil Reserve Air Fleet could be established – but this is beyond the timeframe considered in this study. A possible near-term scenario that could cause apprehension over foreign influence (perhaps reminiscent of the Dubai Ports deal[78]) would be a bid by a foreign government entity to take control of a U.S. launch operator or spaceport that caused the Secretary of Homeland Security to suspect threats to public safety and critical infrastructure. This would require a CFIUS review; however, to date there has been no evidence of such interest by a foreign government entity.

Another possible concern is technology transfer. In this case, other legal and regulatory mechanisms are already in place to control sensitive exports by a U.S. subsidiary of a foreign entity. As noted earlier, the President can exercise the authority to block a foreign acquisition only if the provisions of law do not provide adequate and appropriate authority to protect national security. Clearly, existing export control laws and regulations already address technology transfer concerns, making it unnecessary for the President or Congress to single out the human spaceflight industry for special treatment on this issue that differs from subsidiaries of foreign companies in other industries operating in the United States. For the foreseeable future, the "sensitive" technologies held by commercial human spaceflight companies will be company proprietary designs and processes, rather than militarily significant technologies that aren't available elsewhere on the world market.

Statutory restriction of foreign investment in the U.S. human spaceflight industry would run the risk of limiting or eliminating an important source of investment, possibly undermining business plans

72 OII Fact Sheet.
73 Air Line Pilots Association (ALPA), Fact Sheet: "Timeline of Opposition to Foreign Control of U.S. Airlines," http://www.alpa.org/DesktopModules/ALPA_Documents/ALPA_DocumentsView.aspx?itemid=4505&ModuleId=1316&Tabid=256, accessed January 2008.
74 U.S. Government Accountability Office (GAO), "Issues Relating to Foreign Investment and Control of U.S. Airlines," GAO-04-34R, October 30, 2003.
75 Don Phillips, "U.S. Withdraws Plan on Foreign Investment in Airlines, Disrupting Open-Skies Treaty," *New York Times*, December 6, 2006.
76 Duane Woerth, "Foreign Investment in U.S. Air Carriers," Air Line Pilots Association testimony before the U.S. Senate Committee on Commerce, Science and Transportation, May 9, 2006.
77 David Enrich, Robin Sidel, & Susanne Craig, "World Rides to Wall Street's Rescue: Citigroup, Merrill Tap Foreign-Aid Lifelines; Damage Tops $90 Billion," *Wall Street Journal*, January 16, 2008, p. A1.
78 Eduardo Porter, "Dubai Deal's Collapse Prompts Fears Abroad on Trade With U.S.," *New York Times*, March 10, 2006.

and driving investors to other industries and other countries. At its current stage of evolution, there is no economic or national security reason for this fledgling industry to be forced to face these additional hurdles in an already challenging and risky business climate.

Long-Term Safety Issues

The next several years will bring substantial changes to the global environment for commercial space launch services: new entrants, the evolution or departure of familiar players, the emergence of commercial spaceports, changing needs for cargo and human transport, greater integration of space flights with the air traffic system, and the possibility of orbital habitation by commercial spaceflight participants. These developments will have safety regulation and oversight implications for FAA/AST, affecting the number of personnel required, their mix of expertise, budget requirements, and the need for new licensing and permitting mechanisms.

Pilot, crew, and spaceflight participant training. Spaceflight training traditionally has been a government activity, but this is changing, as evinced by the opening of the private-sector National Aerospace Training and Research (NASTAR) Center[79] in Pennsylvania. Regulation of this activity beyond routine consumer safety protection is premature at this stage, but as the human spaceflight industry stabilizes and more training facilities are developed, some minimum level of standardization will be desirable.

Oversight of spaceports. FAA/AST has issued licenses to five U.S. spaceports: Kodiak, Alaska; Mojave, California; Vandenberg Air Force Base, California; Oklahoma Spaceport; and Wallops Island, Virginia.[80] Ten more have been proposed. If a significant fraction of these are built and become active, FAA/AST will need to expand its cadre of experts to allow continuous, long-term compliance monitoring at the spaceports while developing and refining the procedures for doing so. This may involve more than just launch events. The developers of the future New Mexico spaceport already are hosting annual rocket expositions that include demonstrations of experimental launch technologies.[81] A rocket racing league, analogous to the air races that helped to stimulate the aviation industry decades ago, is being formed.[82] Events such as these draw a large number of attendees, and as with air shows, a range of possible hazards to public safety must be considered.

Point-to-point launch services. Rocket travel between points on Earth, for cargo or people, has many technical, operational, security, and regulatory barriers to overcome. Nevertheless, it is being seriously considered by entrepreneurs today. For point-to-point services to become economically viable, a large number of launch and landing sites would be needed in the U.S. and around the world. Among the implications are the following:

- Site licensing and safety oversight at perhaps dozens of locations, some of which may be close to population centers.
- Inspection of facilities belonging to U.S. licensees at many foreign locations.
- Granting of launching and landing rights to foreign rockets after having reviewed their technical designs, operational procedures, and safety measures.

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79 For more information, see http://www.nastarcenter.com/ (accessed May 16, 2008).

80 FAA/AST, Active Commercial Space Licenses web page, http://www.faa.gov/about/office_org/headquarters_offices/ast/launch_data/current_licenses/ (accessed May 16, 2008).

81 The annual X-Prize Cup began in 2005. For more information, see http://www.xprize.org/space/x-prize-cup (accessed May 16, 2008).

82 Public flight demonstrations were held at the Experimental Aircraft Association's air show in Oshkosh, Wisconsin in summer 2008. (Jeremy Hsu & Tariq Malik, "Rocket Racing League Plane Makes Debut Flight at Oshkosh," *Space News*, August 4, 2008, p. 10.) For more information, see http://www.rocketracingleague.com/ (accessed May 16, 2008).

- Coordination with appropriate U.S. agencies and foreign governments on issues such as space traffic monitoring and control, customs requirements, and export control.

Private space habitats. Bigelow Aerospace of Las Vegas already has orbited two experimental inflatable habitats and has projected a requirement for as many as 12 launches per year starting in 2012 to deploy and service its platforms.[83] FAA/AST currently does not have regulatory authority over orbiting facilities with or without humans aboard. If and when this becomes necessary, an array of new safety issues will be introduced to the licensing and regulatory process, requiring expansion of expertise in areas such as space physiology. Hazards, including radiation exposure and orbital debris, will prompt regulatory involvement in the design, manufacture, deployment, and operation of orbiting platforms. As with today's entrepreneurial launch developments, commercial orbital habitats will need an initial period of relatively light regulation to allow innovation to blossom, avoiding command-and-control solutions that unnecessarily burden an emerging industry.

International differences in regulatory approach. The commercial human spaceflight regulatory regimes that emerge in other parts of the world are likely to differ in various ways from the U.S. approach. For operators using U.S.-built vehicles outside of U.S. jurisdiction, this could raise issues of licensing, liability, and taxation that could impact the global development of the industry. In Europe, for example, the European Aviation Safety Agency (EASA) plans to certify space vehicles that employ aerodynamic flight, and is on a path toward specific safety protection for passengers. This evolution may proceed at a different pace and in a different direction than what is envisioned in the United States. Another concern is that EASA is focusing on aerodynamic craft and not rockets, making it unclear how the latter will be addressed. At some point, cross-border harmonization of regulatory approaches with Europe and other active regions may aid the global expansion of the industry.

These brief examples suggest safety-related issues that are likely to require attention in the next decade. This is not a comprehensive list – unforeseen developments undoubtedly will affect the number, type, and priority ranking of regulatory issues in the future. For example, the more successful the commercial launch industry is, the more flights it will conduct, resulting in public concerns similar to those experienced by airlines and airports in recent decades, such as noise problems and atmospheric pollution. Further study of these and other issues will help U.S. government lawmakers and regulators determine what new and changing requirements may be faced in the years to come in this evolving sphere of activity.

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83 Brian Berger, "Bigelow Aerospace Wants Atlas 5 Rockets for New Space Station," *Space.com*, http://www.space.com/news/080204-bigelow-atlas5-spacestation.html, February 4, 2008 (accessed May 16, 2008).

Appendix A
Methodology for Incorporating Stakeholder Input

Summary

To assure that a comprehensive range of insights was represented in this report, a list of questions drawn from the eight topics in the legislation was sent to a wide range of large and small commercial space flight developers, as well as commercial and State spaceport developers and operators. Other entities receiving the list of questions included members of the Commercial Space Transportation Advisory Committee (COMSTAC), which provides information, advice, and recommendations to the FAA/AST Administrator on matters relating to the U.S. commercial space transportation industry, and the Personal Spaceflight Federation, which represents the majority of potential human space flight providers (vehicles, spaceports, space hotels, prize foundations, and space adventure tours).

Further insight was garnered in meetings with representatives from the National Aeronautics and Space Administration (NASA) Office of Safety and Mission Assurance (S&MA) at NASA Headquarters and the Flight Crew Operations Directorate at the Johnson Space Center. Among many concepts such as a rigorous safety analysis process and human error analysis, NASA's approach to human rating emphasizes establishment of appropriate levels of failure tolerances, which are usually associated with redundancy and reliability requirements. For a system to be human rated, either an appropriate level of redundancy or a high level of reliability must be demonstrated.

Organizations Contacted

The list of questions was sent to the following organizations. Many responses were received in various forms including (1) written comments on list of questions, (2) telephone interviews, and (3) face-to-face conversations. Some organizations contributed to a consolidated response from the Personal Spaceflight Federation.

- American Institute of Aeronautics and Astronautics (AIAA)
- AirLaunch LLC
- Armadillo Aerospace
- Bigelow Aerospace
- Blue Origin LLC
- The Boeing Company, Integrated Defense Systems
- Commercial Space Transportation Advisory Committee (COMSTAC), Reusable Launch Vehicle Working Group
- Garvey Spacecraft Corp.
- Interorbital Systems (IOS)
- Lockheed Martin/United Launch Alliance
- Masten Space Systems
- Mojave Air & Space Port
- NASTAR Training
- National Space Society
- Northrop Grumman Corp.
- Oklahoma Spaceport
- Orbital Outfitters
- Orbital Sciences Corp.
- Personal Spaceflight Federation

- Rocketplane Kistler
- Scaled Composites LLC
- Space Access LLC
- Space Adventures
- SpaceDev
- Space Exploration Technologies Corp. (SpaceX)
- Space Florida
- Spaceport America
- Transformational Space Corp.
- United Space Alliance
- Virgin Galactic
- Virginia Commercial Space Authority
- XCOR Aerospace
- X-Prize Foundation

List of Questions

The list of questions transmitted to the above organizations follows:

Regulation

1) Do you perceive any deficiencies in the commercial licensing and permitting regime established by chapter 701 of title 49 of the United States Code in terms of ensuring safety for:
   (a) the public?
   (b) the crew?
   (c) the spaceflight participants?

2) Assuming that commercial space transport for cargo and passenger operations will emerge in a fashion similar to commercial air transport:
   (a) What should the FAA's regulatory focus be (e.g., integration into the National Airspace System, flight hardware, ground/flight operations, crew training, etc.)?
   (b) Can the necessary regulations be incorporated into existing air transport regulations or does this require a separate regulatory system?

3) Should expendable and reusable vehicles be regulated differently? Should either type of vehicle be regulated differently when carrying humans vs. cargo? Should such regulatory difference be based on exposure of the National Airspace System to the particular type of flight path? Other considerations?

4) Should the U.S. government separate the promotion and regulation of human spaceflight rather than assigning both to the same FAA office? If so, where should the responsibility for promotion reside?

5) Should the U.S. government regulate the extent of foreign ownership or control of human spaceflight companies operating or incorporated in the United States? What would be the benefits or drawbacks of such regulation for your company and for the industry?

Standards and evaluation

1) Should safety standards be uniform for all commercial human spaceflight systems? If not, what factors do you think drive the need for different, augmented, or reduced safety standards? Please provide a rationale in each case.
   (a) Class/type of vehicle (e.g., horizontal takeoff/landing, vertical takeoff/landing, air launch vehicle, etc.).
   (b) Reusability of vehicle (e.g., partly reusable, fully reusable, total expendable, etc.).
   (c) Purpose of flight.
   (d) Other considerations.

2) Should safety standards be uniform for all spaceports supporting commercial human spaceflight? If not, what factors do you think drive the need for different, augmented, or reduced safety standards? Please provide a rationale in each case.
   (a) Ownership/primary responsibility of spaceport (civil/military/commercial).
   (b) Local requirements and laws.
   (c) Scope and limitations of flight vehicle types (e.g., perhaps a spaceport can only accommodate vertical takeoffs or can support multiple launch types but only "runway" landings).
   (d) Scope and limitations of services provided (e.g., perhaps vehicles cannot be serviced at the spaceport, just launched or landed).
   (e) Scope and limitations of types of flights supported (e.g., only supporting tourist flights or science flights).
   (f) Other considerations.

3) If differentiated safety standards are developed, what form do you think would be most helpful? Please provide your rationale.
   (a) A core set of safety standards applicable across the board for all spaceflight systems and/or spaceports with subsets of additional safety requirements specific to a set of factors.
   (b) A set of safety standards based on the core set of standards but individualized for each specific factor.
   (c) A set of independently derived standards for each specific factor.
   (d) A set of safety standards that are individually defined for each spaceport/spacecraft company/spacecraft determined by the specific needs of that entity developed by FAA or a sanctioned third party.
   (e) Spaceport/spacecraft specific safety standards developed by hardware or facility developers that are bought off individually by FAA or a sanctioned third party.

4) What standardization do you think is necessary between spaceport responsibilities and spaceflight companies for ground operations? Do you think the FAA should be responsible for setting these standards or do you think another agency or group would be more appropriate?

5) Do you think existing communication standards (terminology) for aeronautical systems will be sufficient for use in human spaceflight applications or will new or augmented standards be required?

6) Should non-government third parties be used to evaluate the qualification and acceptance of new human spaceflight vehicles?

7) Should non-government experts play a greater role in setting standards and developing regulations? If so, is there a clear path to achieving this in the near future?

8) Do you think your company or other companies entering the commercial human spaceflight industry can provide value added in the formulation of standards and regulation for this industry? If so, what can be done to avoid conflict of interest? In what capacity do you think such companies might be best utilized?
   (a) Individual advisor or consultant.
   (b) Part of a team to formulate standards/regulations.
   (c) Part of an advisory committee.
   (d) Provider of failure or test data.

9) Regardless of whether aspiring commercial spaceflight companies should be involved in setting standards and regulations, do you think there are useful third parties, other than government, that could be helpful in developing standards and regulations for the human spaceflight industry? Or is this function best performed by the government? Examples of additional third parties include FFRDCs, regulatory agencies, and organizations in support of space, safety, and related industries.

10) What would be the most effective venue for commercial human spaceflight companies to challenge or request changes to standards and regulations as methodologies and equipment change and the experience base expands?

Ground operations

1) Is there a need and an emerging market for commercial ground operations, such as mission control, range operations, communications, and telemetry? If so, how should it be regulated?

2) Of the following potential ground operations that may be necessary for commercial human spaceflight, which ones do you see as the responsibility of the commercial spaceflight company, the responsibility of the spaceport, the responsibility of FAA or other government regulatory body?
   (a) Launch control.
   (b) Landing/reentry control.
   (c) Mission control during periods between launch and landing/reentry phases.
   (d) Providing/maintaining communication and/or telemetry to/from spacecraft.
   (e) Providing tracking of spacecraft and other potential interacting bodies during all phases (including range safety).
   (f) Providing potential rescue capability or emergency services including retrieval on both land and sea.

3) For ground operations where multiple spaceflight carriers may be involved, do you favor consolidation of their responsible ground operations with representatives of all carriers (for example, a single mission control room)?

Representative responses to list of questions

General comments

Several respondents disagreed with the timing of the study, citing the lack of relevant flight experience. In general, they felt that the study’s objectives, in whole or in part, could not be fulfilled at this early stage of the industry’s development. Sample comments on this topic follow:

> … no commercial flights have in fact taken place and limited data therefore exists. As such, any attempt to assess the effectiveness of the current regulatory regime for human

> spaceflight operations is premature. This includes attempts to evaluate standards of safety and how those apply to differing concepts of operation. Similarly, the effectiveness of the commercial licensing and permitting regime as regards the safety of the uninvolved public cannot be determined at this time.
>
> This study cannot be data-driven, because there is no data. Inside the Beltway, absent opposition by real world data, institutional preconceptions and assumptions – most of which do not apply to the emerging commercial human spaceflight industry – tend to flourish. This study provides an example of this phenomenon; the questions asked herein embody several such inaccurate preconceptions and mistaken assumptions.

Regulations

On the question of identifying deficiencies in the statutory licensing and permitting regime, one response suggested several wording changes to correct inconsistencies, and also offered the following:

- The code does not address orbital or in-space vehicles. At least one or two commercial companies are working on orbital vehicles that will carry humans into Low Earth Orbit (LEO) within the next 4-5 years.
- Section 70101(a)(7), 70101(b)(3), and 70101(c)(4) should include protection of the crew and spaceflight participants as well as protection of public health and safety.
- Section 70105 (b) (6) (B) should be strengthened to require appropriate reasonable medical and training requirements for spaceflight participants.
- The government should not wait until there is a serious or fatal injury before implementing appropriate safety policies and regulations.

The regulatory breathing space provided in the Commercial Space Launch Amendments Act (CSLAA), of December 2004 allowing unfettered innovation during the industry's gestation, is appreciated. However, some felt that the time allotted (through 2012) would not be enough.

> [The CLSAA] established a moratorium on new regulations, said moratorium to expire after a specified time period. The occurrence of a specified number of flights, or the attainment of a specified level of experience, would have been a better metric for the expiration of the moratorium than a specified period of time… As the expiration date for the moratorium approaches, it is obvious that little more experience has been established since CSLAA was signed into law. This issue really should be revisited, and the current moratorium extended, until a certain numbers of flights have been flown, or a certain amount of flight experience has been gathered.

Some respondents questioned whether sufficient expertise for regulation of commercial human spaceflight existed in FAA/AST or anywhere else outside of the emerging industry itself, as this sample response indicates:

> FAA does not have any personnel experienced in commercial human spaceflight operations. The only relevant base of performance is in industry. The reason this is a problem is that in the absence of commercial human spaceflight experience, FAA personnel draw on their experience in government human spaceflight and in expendable launch vehicle (ELV) cargo operations, and those activities are so different from commercial human spaceflight that they present obstacles to rational regulation… it is important that FAA personnel, and the FAA as an institution, recognize that Shuttle

> experience and ELV experience do not directly translate into helpful paradigms for regulating commercial human spaceflight.

There was disagreement on the question of whether the necessary regulations can be incorporated into existing aircraft regulations, as shown in two conflicting responses and one that takes the middle ground:

> No. This requires a separate regulatory system. The technological basis is simply too different. The mode and the scale of operations is too different.

> The framework for vehicles, training, etc. can be very similar to the environment in air transport. Focus on airspace integration, and specifically transition zones to and from space, would facilitate industry development. Incorporation into the existing regulatory framework has many advantages.

> The necessary regulations could initially be addressed separately and then compared to [National Airspace System] regulations to determine how best to answer the question. If a separate regulatory system is chosen, there should be no overlap and it should be clear which system governs during the flight regime.

Similarly, not everyone agreed on whether expendable and reusable vehicles should be regulated differently:

> We should strive for convergence between regulations for ELVs and RLVs. Ultimately, it is the safety outcome that counts, not whether or not a vehicle is destined to fly again.

> Expendable and reusable vehicles should be regulated differently, in much the same manner as single use gliders of World War II vintage are managed differently than reusable aircraft with life expectancies of thousands of flights.

> Expendable and reusable space vehicles should only be regulated differently to the extent that the vehicles and their operational concepts/plans are different. In addition, vehicles carrying humans should be human-rated. The human rating requirements provide a more reliable vehicle and an abort capability for the onboard crew and spaceflight participants.

Standards and evaluation

Regarding safety standards, and whether they should be uniform across all commercial human spaceflight systems, there were differing interpretations of the question:

> Regulations should not be based on the standards used within individual companies. If those organizations adopt national or international consensus standards, so much the better.

> Safety standards need to be outcome-based rather than prescriptive. As long as the standards are achieved, the way anyone gets there and the nature of the vehicle are relatively unimportant.

> The standard for the safety of the uninvolved public should not discriminate between different kinds of vehicles. [On the other hand…] The technical details of different kinds of systems with different performance and different modes are obviously so different that

> trying to write any kind of regulation that's a "one size fit all" is an enterprise doomed from the start.

The questions on whether safety standards should be uniform for all spaceports, and how spaceports and spaceflight companies should coordinate this, provoked answers such as these:

> All spaceports that are licensed for commercial space activity should be treated in a uniform manner. We are dealing with considerably higher thrusts and energy loads [compared to airports], such that variations are inappropriate… In the interests of public safety, FAA responsibility must extend over the ground operations of commercial space flight.

> FAA safety standards for spaceports should be uniform, in that they should be uniformly absent… Standardization is not necessary between spaceport responsibilities and spaceflight companies. This is an interoperability question. It is decades premature.

Ground operations

Regarding the emergence of commercial ground operations, such as mission control, range operations, communications, and telemetry, the following statements reasonably express the consensus of respondents:

> For the foreseeable future, these are likely to remain very system-specific and therefore the purview of the vehicle operator.

> We expect most of the initial spacecraft developers/operators would design, provide, and perform these functions themselves. However, there could be a market for service providers in the long run.

When asked their opinion about consolidation of ground operations across all carriers (for example, use of a single mission control room), respondents felt this was inadvisable for the foreseeable future.

> Each spaceflight operator should be responsible for its own flight control center which should work in tandem with the airport/spaceports FAA flight control center.

> Consolidation works with commercial aviation primarily because all aircraft work in pretty much the same way. This is unlikely to be the case for commercial space operators. There may be functions that can be consolidated once an understanding of the various operators is achieved. This will require the operators and spaceports to agree on the consolidation and associated processes.

Appendix B
Implementation and Evolution of a Rating System for Vehicle Safety

In the Topic 1 discussion, use of a rating system was proposed under Options 3 and 4. This appendix provides an approach for implementation and evolution of this rating system.

Step 1 – Experimental operations

Step 1a: Development of proposed regulations. Initial activities should be focused on establishing a basic regulatory structure with appropriate feedback mechanisms from industry. This feedback would ensure that future steps incorporate data and lessons learned from early providers. The objectives of the initial regulation are to:

- Do no harm in reducing the level of protection offered to third parties. The existing case-by-case licensing of launches and reentries by FAA/AST is adequate to meet this need.
- Achieve industry participation in collecting data/experience necessary to establish evolving regulations as the industry matures. This requires a delicate balance between intrusiveness and insight.

On one hand, it would be desirable to collect virtually all contractor-produced data that may become relevant to safety, and then use these data to provide quantifiable safety evaluation results to the public. This may impart a significant burden on the industry participants, yet the ratings provided to the public would have little significant data to support the results. At the other end of the regulatory spectrum, all data collection would be voluntary, and no evaluation results would initially be shared with the public. This provides a significantly more open regulatory environment in which the entrepreneurs received less oversight, and thus should have more incentive to attempt innovative approaches with potentially higher gains. However, providers may choose not to participate in data collection, and thus FAA/AST would lose the quantifiable experience that would be needed to define later requirements or provide the public with an independent safety evaluation.

Part of the methodology formulation would include development of a standardized data collection system (including metadata) that provides structure and uniformity to the data being generated. With FAA/AST concurrence, individual providers would be enabled to modify data collection forms based on unique system characteristics.

Step 1b: Gather industry feedback. The Proposed Initial Regulation would be provided to industry representatives. With sponsorship by FAA/AST, the regulatory development team members would meet with industry representatives to work an agreement on an accepted analytical approach, with emphasis on the first step. This activity would include iteration with industry stakeholders on items, potentially including data sheet questions, format, timeliness, configuration control, and independent verification of inputs. The timeframe provides an opportunity to survey the industry and gather insights about their willingness to provide data (voluntary vs. mandatory compliance), as well as feedback about their willingness to provide evaluation results to the public. A reasonable assumption is that the providers whose designs are the most mature, robust, and risk-tolerant would be the most likely to embrace this system.

Step 1c: Development of initial regulations. Once concurrence with industry is achieved (or unresolved issues are defined), coordination with FAA/AST for the final release of Step 1 regulations should be undertaken. This period would be used to balance feedback from industry with the ultimate responsibility of the FAA/AST to protect public safety, independent of whether their assessment results are initially provided to the public.

If the data collection requirements were adequately filtered to only those key drivers that influence overall safety/survivability, the impact to industry would be minimized. Collection of data by FAA/AST would benefit the industry as a whole by developing a more rapid understanding of the dependencies of design and operations approaches to overall safety levels. This parallels the experience in the skydiving, parasailing, and bungee jumping industries, in which good insight into industry performance is beneficial in raising venture capital funding, acquiring insurance at reasonable rates, and generating positive press. A process must be developed for FAA/AST to perform periodic checks on provider data to ensure accuracy.

Independently of which option is selected, a data standard must be developed for mishap/accident-related safety reporting. This may include such items as: identification of root causes (including categorization as system-specific or industry endemic), and identification of lessons learned. Initially, safety evaluations would be based simply on some key individual metrics (e.g., design margin, manufacturing process/quality, and number of tests conducted in a relevant environment before human-carrying flights begin). Safety reporting is discussed in more detail in Topics 6 & 7.

Step 2 – Adventure operations

By the initiation of proposed Step 2, the industry will likely be transitioning from an experimental, high-risk industry to a more mainstream activity serving a larger cross-section of the population. This corresponds to sufficiently high flight rates to render the data set for individual robustness parameters statistically significant.

The formal transition from Step 1 to Step 2 would occur when FAA/AST determines that it has collected a statistically significant data set for individual safety-related design, testing, and operations parameters. FAA/AST would then generate a star rating (or equivalent) that correlates specific <u>individual</u> robustness parameters (e.g., design margin, degree of testing, escape provisions, concept of operations, operating envelope, etc.) to risk (in terms of potential for loss of life). The criteria that govern this transition will be developed during Step 1. Our expectation is that this will happen when at least one provider has achieved 25 or more flights or the industry as a whole has achieved at least 50 flights. The exact timing will depend on the rate at which this experience is gained, but our assumption is that this will occur in the 3-5 year timeframe.

At the start of this step, FAA/AST would determine whether updates to the data collection format and/or reporting requirements are required, based on experience gained during Step 1. In addition, FAA/AST would establish formal guidelines that differentiate licenses for Adventure Operations from those for Experimental Operations. To qualify for the higher level of license, providers must agree to provide data to FAA/AST, and must submit to a safety evaluation (including public dissemination of results). Qualification for an Adventure Operations license would require achievement of a minimum set of star ratings (see below for discussion on defining what the minimum should be). Providers who choose not to apply for Adventure Operations licenses may still fly under an Experimental Operations license, but this would likely limit their market capture.

For the remainder of Step 2, providers would continue operations for experimental and adventure classes of customers. Potential customers would become more knowledgeable about the safety of the vehicles due to the availability of FAA/AST evaluation results, and their selection of providers would reflect that knowledge. Providers with higher safety ratings would be likely to capture a larger share of the market (independent of ticket price considerations), with lower insurance costs, providing incentives to improve safety across the industry.

Step 3 – Commercial operations

By the beginning of Step 3, perception of personal space travel is likely to have evolved beyond a high-risk, action/adventure activity to a point where it is ready to become a mainstream activity. This is representative of the early days of commercial aircraft passenger transport. The industry would support significantly higher flight rates, such that the data collected by FAA/AST would allow a statistically meaningful examination of the interrelationship between the robustness parameters and overall flight safety. These data would be used to provide a combined rating (e.g., an overall 5-star safety rating), analogous to what is currently done in other industries. The criteria that govern this transition will be developed during Step 2. Our expectation is that this will happen when at least one provider has achieved 100 or more flights, or the industry as a whole has achieved at least 250 flights. The exact timing depends on the rate at which this experience is gained (flight rate), but our assumption is that this will be in the 10-15 year timeframe. A proposed method for combining these robustness parameters into a single evaluation factor is described below.

Analysis of robustness parameters is anticipated to be at least as valuable to the service provider as it is to FAA/AST. For industry, this should help to guide operations protocols, testing, and maintenance towards more effective practices, as well as providing insight to guide related follow-on efforts. For FAA/AST, the existence of a large data set would allow higher fidelity analyses to be performed on subsets of the data, which would help determine if commercial human spaceflight in Step 3 should be regulated by class or type of service, purpose of flight, or other considerations.

When initiating this step, FAA/AST would again determine whether an update to the data collection format and/or reporting requirements are required, based on experience gained during Step 2. In addition, FAA/AST would establish formal guidelines that differentiate licenses for Commercial Operations from lower-level licenses for Adventure Operations and Experimental Operations (see below for discussion on defining what the minimum should be). To qualify for this higher level of license, providers would need to achieve a minimum overall safety rating. Providers who choose not to apply for Commercial Operations licenses would still be permitted to fly under an Adventure or Experimental Operations license, but this would likely limit their market share.

Methodology for combining individual safety characteristics into an overall safety rating

After the industry has built up a statistical database of flight experience, techniques for probabilistic statistical analysis can be meaningfully used. These analyses can quantify failure mode probabilities by statistical comparisons of the probability distribution functions of different robustness parameters against the likelihood of the system being able to withstand them. Such methodologies must also account for the effects of gradual degradation through aging and continued use, modified by systematic maintenance, inspection and upgrades.

A consistent framework must be developed to determine the probability of death or injury of a spaceflight participant resulting from an anomalous event or series of events on any subject RLV as a function of a reasonable confidence interval. This probability would, of course, be affected by the type and size of vehicle, the degree of verification of the technologies employed, the nature, sophistication, and level of diligence used for the design, the quality assurance and flight readiness processes employed and their relation to the frequency and duration of utilization, and qualification of the flight support infrastructure.

Different levels and combinations of analysis, ground and flight test will be appropriate for RLVs of varying levels of sophistication and performance. These can be combined using a Bayesian[84] approach to develop a relationship between failure probabilities and confidence levels. This methodology can also be employed to characterize the relationship between types of analysis, thoroughness and extent of ground and flight test programs, and the level and sophistication of vehicle health management and incipient anomaly mitigation controls. The recommended approach is to develop general metrics to help establish key criteria that, used together, provide a determination of Personnel Risk Exposure (PRE). One such metric, discussed below, is the Flight Test Equivalence (FTE) parameter. This parameter is designed as a roll-up to capture the thoroughness of a test and development program. Ultimately, the thoroughness of a test and development program can be related to its effect on the probability of occurrence of the failure modes it is expected to address.

A conceptual approach for addressing commercial RLV flight test verification, based on linking statistical analysis to testing and design analysis, is described by means of the example below:

(1) Generate an FTE parameter based on both the level of design margin and a Test Thoroughness Index (TTI) (Figure 4). The TTI value is a function of the number of tests, quality of testing, process control, and relevant team experience. Example inputs are the design analysis that was performed, concept of operations development including training/skill set, process controls/rigor, physical and functional redundancy, reliability assessments, failure modes and effects analysis/controls, performance repeatability/variability, and degree of incremental flight test employed.

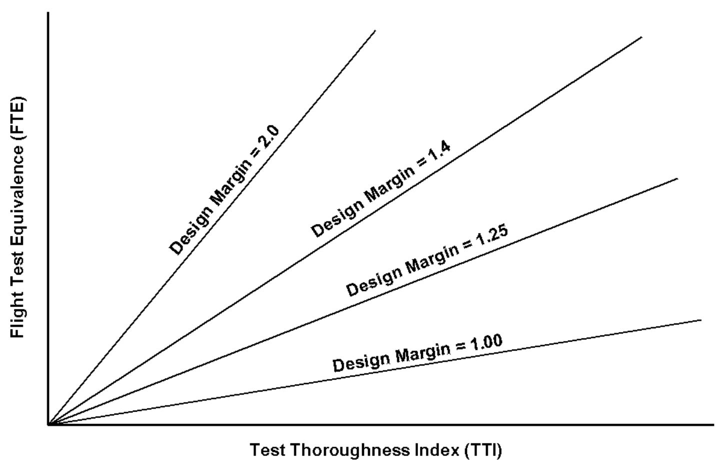

Figure 4. Flight Test Equivalence (FTE), Notional Depiction

(2) Employ existing statistical relationships between the Total Equivalent Flight Tests (TEFT) and the confidence level desired (e.g., 50%, 90%) to develop an Equivalent Vehicle Reliability (EVR) parameter (Figure 5). The TEFT is equal to the sum of the FTE plus the product of the Data Collection Ratio (DCR) and the number of actual flight tests. The DCR is a factor initially determined by the degree of in-flight and post-flight data collection employed. Factors that determine the DCR include the degree of Integrated Vehicle Health Management (IVHM) employed and the degree of between-flight measurements/inspections/testing and data collected.

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[84] "Bayesian" refers to statistical methods that regard parameters of a population as random variables having known probability distributions based on prior knowledge and accumulated experience.

Once flight testing commences, the DCR would be adjusted based on the relevancy of flight data collected to pre-flight predictions. The DCR ratio will increase with high flight-to-test correlations and decrease as a function of unplanned/unpredicted anomalies. The intent of this activity to generate draft data request sheets that, once completed, will capture key test experience characteristics.

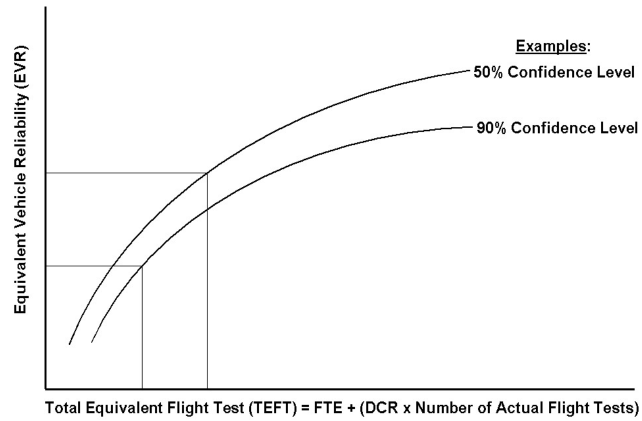

Figure 5. Equivalent Vehicle Reliability (EVR), Notional Depiction

(3) Correlate the EVR with the Personnel Survival Factor (PSF) using traditional mathematical techniques to develop an estimate of Personnel Casualty Expectation (PCE) or more commonly Loss of Life Potential (Figure 6). The PSF is determined by factors such as crew escape, completeness of the IVHM to avoid/preempt failure, and abort options and flexibility. In its simplest form, the PSF ratio for a vehicle with an 80% escape system reliability and 90% preemptive warning success would be [1/(1 – escape system reliability)] x preemptive warning success. That is, PSF = [1/(1 - 0.8) x 0.9] = 4.5. In the notional depiction in Figure 4, to achieve a given level of loss of life potential, the designer could trade the degree of equivalent vehicle reliability with PSF, which includes the escape system.

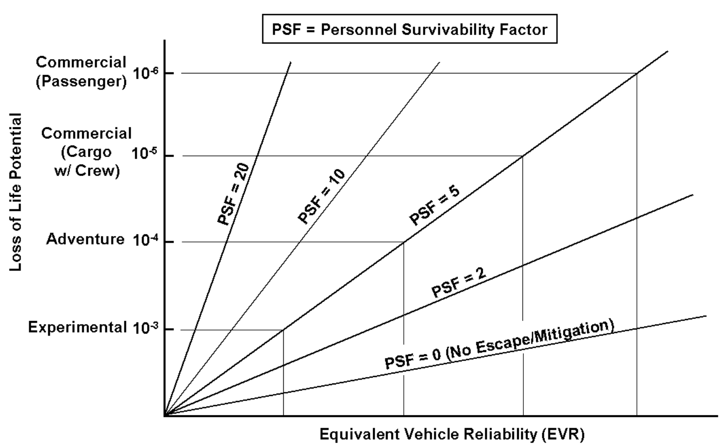

Figure 6. On-board Personnel Survivability, Notional Depiction

The assignment of an overall star rating for the vehicle is a direct measure of the loss of life potential shown in Figure 6. With data collected from the first two steps, FAA/AST would determine the threshold values between what is required for each star rating, as well as the minimum threshold required to achieve a Commercial Operations license.

(4) Using comparisons of accidents/fatalities per million participants and per activity for other high risk activities, develop parametric relationships for initial "experimental" operations, lower risk "adventure" operations, and ultimately, "commercial" operations. These guidelines would then be suitable for working the problem backwards to understand the relationship between design approach, test/process approach, and numbers of flight tests required to achieve various levels of operation. First, quantitative criteria must be developed for maximum allowable participant casualty expectations for various categories of RLV missions, e.g., commercial, adventure, experimental, etc. These levels can be related to existing casualty expectation criteria from previously characterized activities. The action adventure industry comprising such activities as bungee jumping, ultra-light aircraft flight, ballooning, and mountain climbing can be leveraged to provide some precedence.

Acceptable risk levels for crews may be significantly higher than for spaceflight participants. Using the above criteria, parameters can be derived that balance required testing, analysis, and training with acceptable risk for both crew and participants. This process strongly leverages industry experience and can solidly leverage accepted mathematical techniques for determination of exposure to risk. Statistical relationships derived at The Aerospace Corporation and elsewhere can be used to generate a minimum number of flights that must be flown to predict reliability as a function of confidence level. Quantitative and qualitative databases have been developed that relate system performance (reliability, mission success) to processes employed (such as specifications, standards, and configuration management), testing duration, design margin, etc. Failures have been correlated by mission phase and subsystem to overall mission reliability. Data and analyses of this type would be critical inputs in relating the degree of testing for specific subsystems/technologies to developing the TTI, FTE and PSF relationships. Existing experience and databases relating to degrees of testing, design margin, and reliability have already been achieved for various categories of launch components. These existing analyses could be updated to include the most current rocket propulsion system data as well as any data available from the personnel spaceflight industry.

This approach would require minor adaptation to accommodate systems designed for both remote operation and operation with a crew. One option would be simply to dictate that the vehicle must be remotely operated until the minimum level of reliability acceptable for crew is achieved. A second, more risky approach would be to extend the analysis to high levels of ground testing and relate the degree of ground testing necessary to enable initiation of incremental human flight.

Similarly the third party risk assessment process must also evolve. At the present time, third party risk is addressed only on a per flight basis, specifically 30×10^{-6} loss of life per flight. Clearly, as flight rates increase from ones to tens of flights per year per provider to 1,000 to 10,000 flights per year, the cumulative consequence of both loss of life per provider and for the industry as a whole to the general public would increase substantially. At that point, the per-flight allowable accident rates would be reduced, and the cumulative consequence to third parties would be equal to or less than that of commercial aircraft operations.

Appendix C
Mission Assurance Principles and Practice

Mission Assurance as a Basis for Standards

Mission assurance is the disciplined application of general systems engineering, quality, and management principles toward achieving mission success. It focuses on the detailed engineering of the launch system using independent technical assessments throughout the entire concept and requirements definition, design, development, production, test, deployment, and operations phases.

Effective mission assurance is critical because space is an unforgiving business. Orbital launch vehicle mission failures in the 1990s resulted in $11 billion in lost assets. Many of these losses resulted from the use of unvalidated acquisition practices – the "acquisition reform" and "faster, better, cheaper" approaches that grew popular after the Cold War. More significant than the loss in dollars was the loss of vital military and intelligence capabilities and opportunities for space exploration, research, and commerce.

Since 1999, the national security space industry has been recovering from those losses by reestablishing tried-and-true practices that emphasize mission success over schedule and cost reduction. This "back-to-basics" approach recognizes that optimum cost performance results from doing the job right the first time and achieving 100-percent mission success. An obvious part of this accountability entails objective assessment and independent monitoring of program executability.[85]

This process has been applied to the design, development, and operation of several hundred launches, including the Atlas, Delta, Inertial Upper Stage, and Titan launch system variants. The process has also been tailored to support other government and commercial launches, including the Atlas 5 and Delta 4 launch systems being procured through the Evolved Expendable Launch Vehicle program. The process has resolved major programmatic and technical challenges, ranging from the conversion of the Titan 2 intercontinental ballistic missiles into reliable launch vehicles, to the return to expendable launch vehicle programs after the loss of the space shuttle *Challenger*. The contributions of the launch verification process to system reliability may be difficult to quantify; nonetheless, government launch programs that include independent design certification exhibit a tenfold reduction of risk as compared with commercial launch programs for the first three flights.[86] The *Columbia* Accident Investigation Board found that independent launch verification has significantly reduced engineering errors, resulting in 2.9 percent "probability-of-failure" rate for expendable launch vehicles, compared to 14.6 percent in the commercial sector."[87]

A Ten-Step Approach to Independent Review

A summary of historical best practices for independent review teams is presented below[88]. This approach is based on determination and evaluation of the main items believed to pose the greatest risk to space launch missions.

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85 W. F. Ballhaus, Jr., "From the President's Desk," *Crosslink*, The Aerospace Corporation, v. 8, n. 2, Fall 2007, p. 1.

86 R. F. Johnson, "The Path to Mission Success: The Aerospace Role in Launch Certification," *Crosslink*, The Aerospace Corporation, v. 4., n. 1., Winter 2002/2003, p. 4.

87 *Columbia* Accident Investigation Board Report, Vol. 1, August 2003, p. 184, and E. J. Tomei, Jr., "ELV Launch Risk Assessment Briefing," 3rd Government/Industry Mission Assurance Forum, The Aerospace Corporation, September 24, 2002.

88 T. Freitag, & B. Higuera, "The Role of Independent Assessments for Mission Readiness," *Crosslink*, The Aerospace Corporation, v. 8, n. 2., Fall 2007, pp. 6-9.

1. Test-Like-You-Fly Exceptions
   One of the most important lessons in the space launch business is that hardware and software must be tested in the same manner that they will be flown. Exceptions to the test-like-you-fly approach have resulted in mission failures and represent an increased program risk that must be addressed.
2. Critical Qualification Margins
   Qualification margins of critical items must be checked. Hardware with minimal safety margins poses an increased risk of failure because of variations in mechanical properties, component performance, or other critical measures.
3. First-Flight Items
   First-flight items receive increased scrutiny because they have not yet performed under actual flight conditions. At each review, the review team requests a list of first-flight items and a clear description of the qualification procedures performed on them.
4. Single-Point Failures
   Redundancy in a system significantly reduces the probability of failure. The manufacturing documentation for hardware subject to single-point failures is carefully reviewed.
5. Nonconformance
   Hardware or software that does not meet specifications is either reworked or reevaluated for use "as is." Panel members review the actions taken to correct these nonconformances and assess them for adequacy.
6. Anomalies
   Situations where hardware or software did not perform as expected are referred to as anomalies. Careful review and analysis are required to determine root cause and verify that the anomaly will not recur in flight or have a significant impact on the mission.
7. Escapes
   Escapes represent events in which the contractor missed something, such as releasing hardware that did not receive all of the appropriate testing. The review team strives to identify escapes as part of the pedigree review and the hardware acceptance review. The review team requests a list of contractor escapes as part of the review briefing. Once identified, escapes are carefully reviewed to assess the likely impact on mission performance, and recommendations are made for corrective action. These may include additional testing, analysis, or simply use "as is."
8. Unverified Failures
   Unverified failures are those for which the root cause is not identified. Without a root cause, it is difficult to know what to fix, nor can there be assurance that the failure will not occur in flight. In these cases, fishbone diagrams are created, which detail cause-and-effect relationships and potential root causes and remedies.
9. Out-of-Position/Sequence Work
   Occasionally contractors will deviate from their paperwork and perform work out of sequence or in a configuration different from the one used to build up the original assembly. This can result in assembly errors that need to be addressed or test results that need to be revalidated. The review team reviews these cases to evaluate their impact on the mission and to offer recommendations.
10. Out-of-Family Results
    Out-of-family results are carefully reviewed because they often indicate that something has changed in the production process that may cause a reduction in performance. The use of statistical process control is an effective means to identify out-of-family results.

Appendix D
Applicable Air Force and NASA Documents on Space Safety

Current applicability for commercial human spaceflight

- **Air Force Space Command Manual (AFSPCMAN) 91-710**

  Volume 1 – Air Force Space Command Range Safety Policies and Procedures: Some of the specific responsible parties would need to be adapted for different spaceports and/authorities; however this could provide a template to address this.

  Volume 2 – Flight Safety Requirements: Some of the specific responsible parties would need to be adapted for different spaceports and/authorities; however this could provide a template to address this. This addresses flight safety, but not from a human participant standpoint.

  Volume 3 – Launch Vehicles, Payloads, and Ground Support Systems Requirements: Some of the specific responsible parties would need to be adapted for different spaceports and/authorities; however this could provide a template to address this. This includes safety concerns as well as ground safety requirements and operational constraints for monitoring (flight support).

  Volume 5 – Facilities and Structures: Some of the specific responsible parties would need to be adapted for different spaceports and/authorities; however this could provide a template to address this.

  Volume 6 – Ground and Launch Personnel, Equipment, Systems, and Material Operations Safety Requirements: Some of the specific responsible parties would need to be adapted for different spaceports and/authorities; however this could provide a template to address this.

- **NASA HQ Office of Space Science, Office Work Instruction HQOWI8630-S008B – Launch Preparation Activities:** Addresses how to comply with National Environmental Policy Act (NEPA) compliance documentation, (b) Nuclear Safety Launch Approval (if sufficient nuclear material is carried on the spacecraft), and (c) appropriate Contingency Plans.

- **NPR 8705.2B, Human-Rating Requirements for Space Systems** (revised May 6, 2008)**:** Useful information relevant to FAA regulatory needs. Human spaceflight organizations may want to review/implement this document before new FAA safety requirements are imposed to limit potential impact on designs and provide safety for crew and participants.

- **NASA Procedural Requirement (NPR) 8715.3B – NASA General Safety Program Requirements**: Although some of the requirements here are not applicable for the current FAA charter, others, including institutional, programmatic, and other safety aspects, may be part of the current charter. The additional not-yet-applicable sections may also become applicable as the FAA safety charter changes.

- **NPR 8715.5 – Range Safety Program**: This data and requirement set may be directly applicable.

Possible applicability for future commercial human spaceflight safety requirements

- **CxP 70024 – Constellation Program Human-Systems Integration Requirements:** Although specific to Constellation, may be able to provide a template for addressing human spaceflight requirements for safety of crew and participants.

- **Phase I (Mir) Lessons Learned:** As the FAA charter adapts and addresses more aspects of human spaceflight safety and/or as international endeavors are created that might include multinational partners, these lessons may become applicable.

- **NASA Policy Directive (NPD) 8700.1C – NASA Policy for Safety and Mission Success:** As the FAA charter adapts and addresses more aspects of human spaceflight safety, this provides a useful starting point for addressing a commercial human spaceflight safety program/policy.

- **NASA Special Publication 6104, "A Perspective on the Human-Rating Process of US Spacecraft: Both Past and Present,"** February 1995, and **NASA Report T98-10212, "A Review of Man-Rating in Past and Current Manned Space Flight Programs,"** May 20, 1988: Human spaceflight organizations may want to review/implement these documents before new FAA safety requirements are implemented.

- **NASA Engineering and Safety Center Technical Report RP-06-108, "Design Development Test and Evaluation (DDT&E) Considerations for Safe and Reliable Human Rated Spacecraft Systems,"** Version 1.0, Vols. 1 and 2, May 1, 2007 and June 14, 2007: Human spaceflight organizations may want to review/implement this document before new FAA safety requirements are imposed.

- **National Space Transportation System (NSTS) 08080-1 – Manned Spacecraft Criteria and Standards:** Listing of historical design criteria and standards for manned spacecraft. Contains considerable lessons that may be of use as the FAA charter changes.

- **Top Ten Skylab Lessons Learned:** As the FAA charter adapts and addresses more aspects of human spaceflight safety and/or as long duration flight opportunities are created, these lessons may become applicable.